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BULLETIN
of the
American Association *of* Petroleum Geologists

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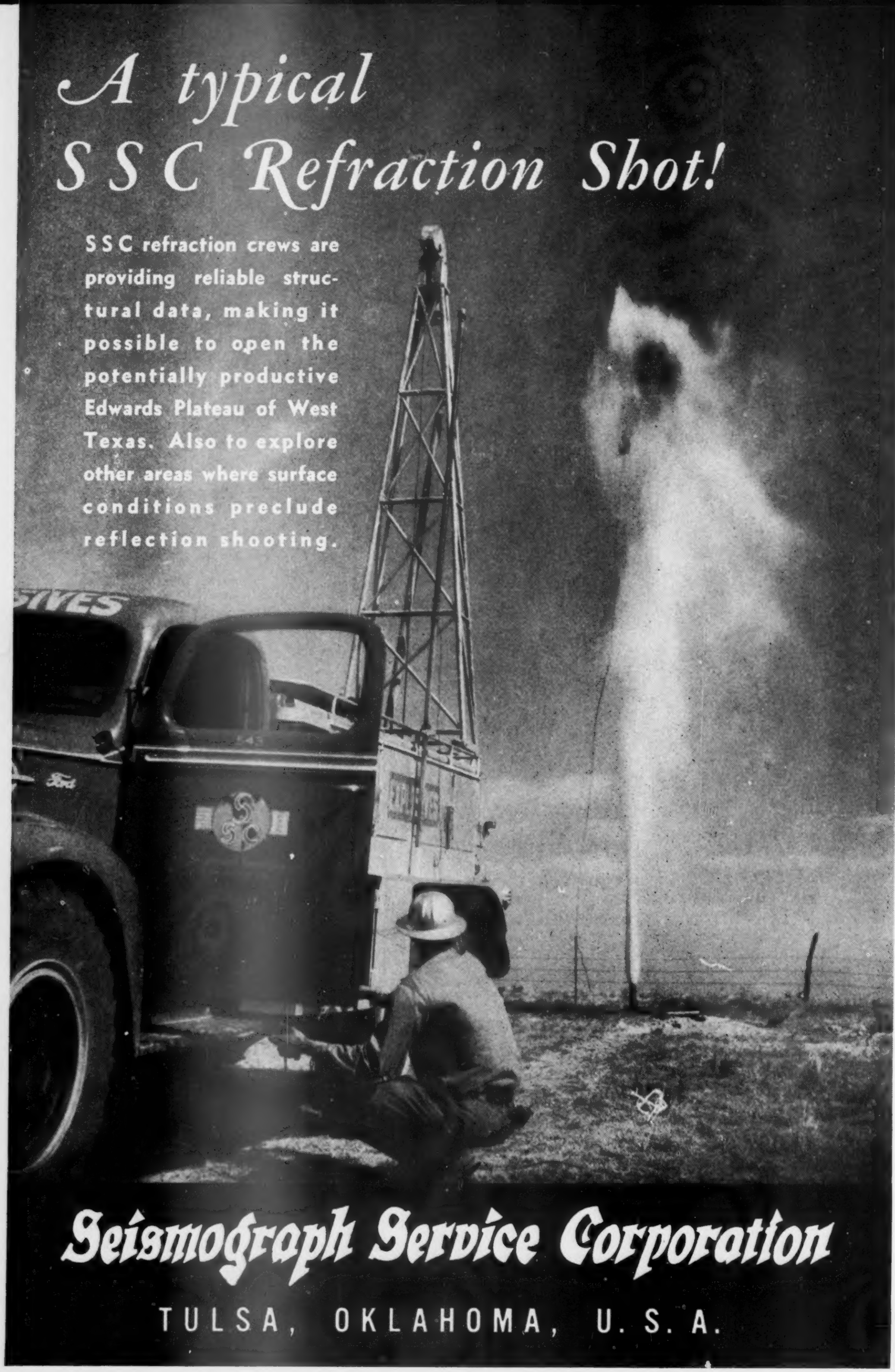
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BULLETIN

of the

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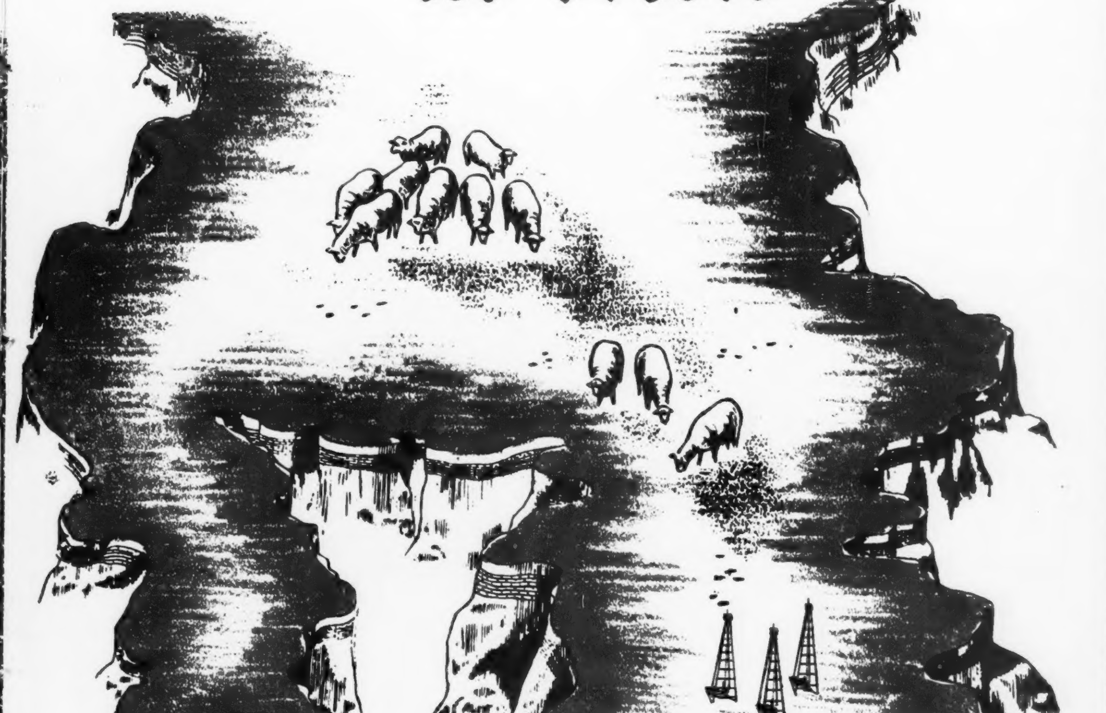

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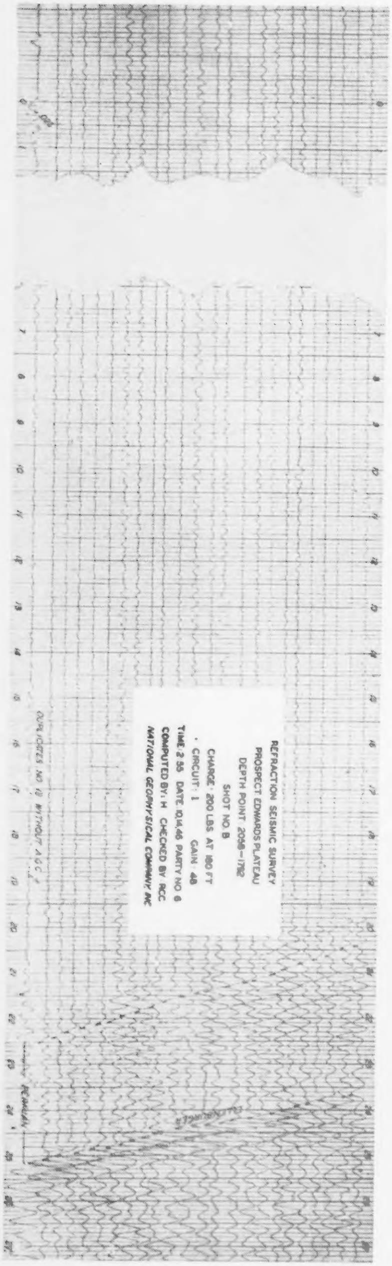
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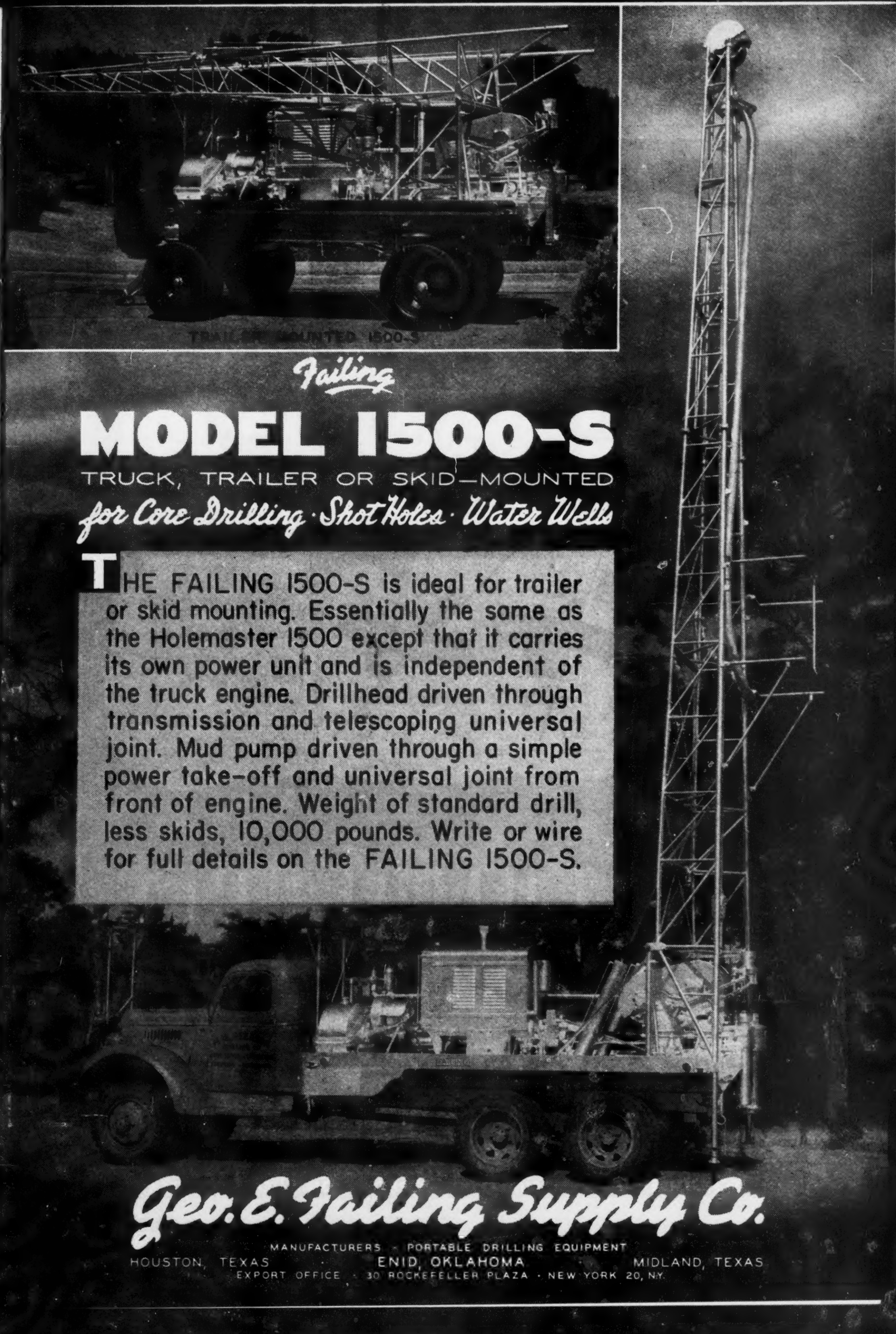
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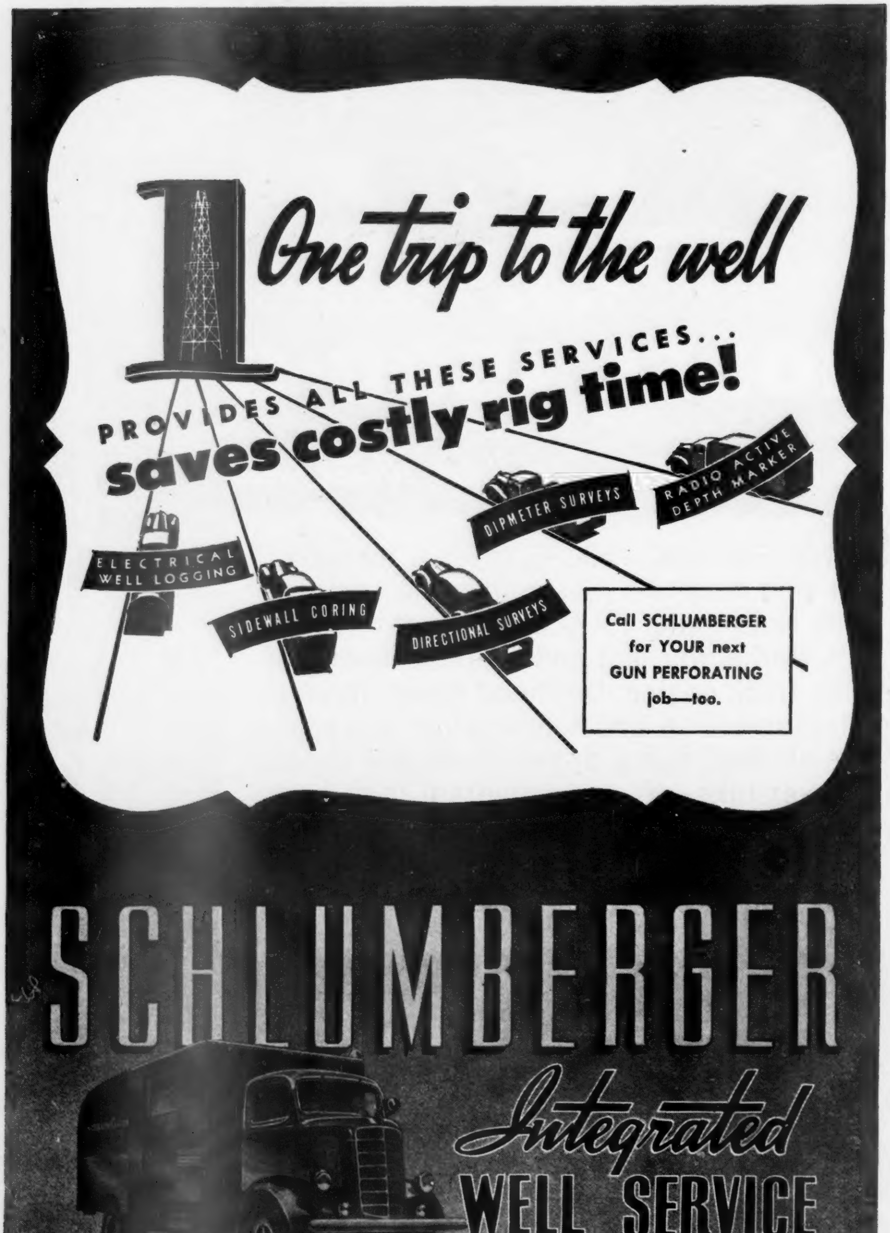
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Volume 31 Number 1

BULLETIN
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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JANUARY, 1947

STRATIGRAPHY OF WESTERN AUSTRALIA*

CURT TEICHERT†
Melbourne, Australia

ABSTRACT

The state of Western Australia covers about one-third of the Australian continent, that is, almost a million square miles. As far as known not less than one-third of this area is underlain by sedimentary rocks, not including the pre-Cambrian. All the major geological systems are represented, with the exception of the Silurian, but the occurrence of Triassic is doubtful. The stratigraphical sequences and the distribution of sedimentary rocks are described according to periods, beginning with the Cambrian and proceeding to the Pleistocene. Eventually, the sedimentary areas are classified according to their significance and grouped in the following categories: (1) scattered outcrop areas, (2) large, comparatively thin sheets, (3) coastal basins, (4) major basins. Thicknesses in (1) and (2) do not exceed 2,000 feet. Basins of group (3) are little known, except for the southwest coastal basin with sediments probably 6,000–7,000 feet thick. There are three major basins of type (4), with thicknesses exceeding 10,000 feet, but one of them has only been recently discovered and is as yet almost unknown. The other two are: the Desert basin, with Devonian to Jurassic stratigraphy and thicknesses probably up to 14,000 feet, and the North-West basin, with Permian to Tertiary strata, with a known maximum thickness of more than 14,000 feet. These two basins are geosynclinal in type. They are idiogeosynclines in Umbgrove's, or paralic basins in Tercier's, terminology. The economic significance of these facts is briefly discussed. In both basins there is an abundance of potential source, reservoir, and cover rocks.

INTRODUCTION

Western Australia is the largest of the six states comprising the Australian Commonwealth. With an area of 975,920 square miles it occupies about one-third of the continent of Australia. Many of the sedimentary regions are as yet little explored and their boundaries ill defined, but it may be estimated that about one-third of the state, approximately 325,000 square miles, is made up of sedimentary rocks younger than pre-Cambrian in age. These sediments range in age from the Cambrian to the Pleistocene. In some parts of the country they form no more than a thin sheet on top of the pre-Cambrian; in others large sedimentary basins are present with thicknesses of many thousands of feet.

An excellent summary of the stratigraphy of Western Australia, representing

* This paper, with the exception of the chapter on "Stratigraphical Terminology," is an original publication in the *Journal and Proceedings of the Royal Society of New South Wales* for 1946.

† Assistant chief Government geologist, Mines Department, Melbourne, C.2. (Formerly of the University of Western Australia.)

the state of knowledge in approximately the year 1937, was included in a paper by Clarke in 1938.[1]

Of the facts that have come to light since that time some have been published in papers in various periodicals, a few have been incorporated in the stratigraphical part of a recent textbook for Western Australian students,[2] and many are as yet unpublished.

The present paper is the result of a stock-taking of existing knowledge and many previously unpublished observations and conclusions may be found scattered throughout the text.

The stratigraphy of the pre-Cambrian sediments of Western Australia is not included in this paper, because it has been adequately described in the publications already referred to.

Apologies are offered to the reader for the personal note which is perhaps too apparent in many places in this paper. However, the time is not yet ripe for the compilation of a standard text on the subject and the paper emerges as the result of eight years of personal experience in Western Australia without which it could not of course have been written.

This paper is not a historical treatise and references to earlier papers are, therefore, not exhaustive. The approach to the description of the rocks is somewhat different for different periods. Thus, Permian sections are described from north to south and Tertiary rocks in the reversed geographical order. It was thought best as far as possible to proceed from the better known to the less known sections and from the more important to the less important areas.

Throughout the text numerous references may be found to deep bores. It should be noted that few of these are diamond-drill bores and even thus cores are not everywhere available. Either no cores were kept or the cores are not easily accessible at present. Most deep bores in Western Australia are percussion bores from which no samples are available. The only sources of information are the original driller's logs which are rarely satisfactory from the geologist's point of view. The logs of many early bores may be found in the "Report of Interstate Conference on Artesian Water" (Sydney, 1912), pp. 130–58; others were obtained by courtesy of the Geological Survey and of the Public Works Department, Perth. Unless otherwise stated, all geological deductions regarding bore sections are based on such logs.

STRATIGRAPHICAL TERMINOLOGY

As is well known, the rigid rules of stratigraphic nomenclature generally accepted by American geologists are not enforced in British countries and in

[1] E. de C. Clarke, "Middle and West Australia," *Region. Geol. d. Erde*, Band 1, Abschn. VII. 58 pp. Leipzig (1938). Very important to this day is also the earlier account by A. Gibb Maitland, "A Summary of the Geology of Western Australia," *Mining Handbook, Geol. Survey Western Australia*, Mem. 1 (1919). 55 pp.

[2] E. de C. Clarke, R. T. Prider, and C. Teichert, *Elements of Geology for Western Australian Students*, pp. 232–90. Perth (1944).

Europe. For example, in British publications the word "formation" is not usually applied in the same sense in which one has become accustomed to seeing it used in the works of American stratigraphers. Words such as "group" and "series" are used much more loosely; it is not uncommon to see a "group" or a "stage" subdivided into "series"; "stages" are occasionally designated by fossil names, not by locality names as in America; stratigraphical units are loosely referred to by way of rock names (sandstones, shales, *et cetera*), or they are simply called "beds," and successive "beds" or zones or other units may be classified by means of a numbering or lettering system which in some cases (in the Paleozoic of Norway and Bohemia) has been carried to a high degree of complexity without thereby facilitating matters. Thus, for example, $3c\gamma$ in the Ordovician of Norway is the equivalent of $B3\beta$-γ in Estonia, and of $d\gamma 1$ in Bohemia.

Australia is no exception and no guiding nomenclatorial principles have so far been adopted by stratigraphers in this country. The first attempt to introduce American terminology into Australian literature was made recently by officers of the Mineral Resources Survey in Canberra in connection with a revision of certain Tertiary sections in Victoria.[3]

While it is recognized in principle that conformity of terminology in the two countries is a highly desirable aim, the writer abstains from proposing major terminological changes in the present paper. Such changes can be introduced only gradually as the knowledge of sedimentary rocks of Western Australia advances. This paper is concerned with the presentation of the present state of our knowledge and if the terminology of the beds may seem inconsistent, it must be realized that this state of affairs results from the rather piece-meal way in which our knowledge of these rocks has been accumulated.

A serious obstacle to the proper naming of stratigraphical units (formations or stages or any other units that are commonly associated with locality names), an obstacle which it is perhaps difficult to realize outside Australia, is the fact that large tracts of country are devoid of any geographical features that could reasonably be named. Large parts of Western Australia are peneplaned down to an extraordinary degree of perfection; major drainage channels are few, and residual hills may be far between, and the writer has studied more than one important stratigraphical section in country where it would have been impossible to point out any topographical feature to which a geographical name could have been attached, and where a lonely gum tree provided the only landmark for miles.[4]

Such native names as are available are few and far between; furthermore, many are cumbersome and difficult to pronounce (Mooroelloojuggoo, Dotharalawooralpooka). On the other hand, many European names that have been bestowed on certain topographical features are of such commonplace nature that

[3] I. Crespin, "The Stratigraphy of the Tertiary Marine Rocks in Gippsland, Victoria," *Dept. of Supply and Shipping, Min. Resourc. Survey Bull. 9* (Pal. Ser. 4). Canberra (1943). (With foreword by H. G. Raggatt.)

[4] See, for example, C. Teichert, "Bradyodont Sharks in the Permian of Western Australia," *Amer. Jour. Sci.*, Vol. 241 (1943), footnote, p. 548.

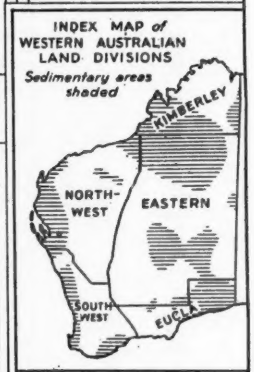
STRATIGRAPHICAL TABLE *of* WESTERN AUSTRALIA

Compiled by *CURT TEICHERT*

		LAND DIVISIONS (*See inset map*)				
		KIMBERLEY	NORTH-WEST	SOUTH-WEST	EUCLA	EASTERN
Pleistocene		Marine and lacustrine clays		*Marl deposits* of Coastal Plain *Cave deposits* with extinct marsupial fauna	Sedimentary fillings of many dry salt lakes, deep leads, etc., probably date back to this period	
Pleistocene		Deposits of a *Glacial* stage: *Dune limestones* ("Coastal Limestone series") Deposits of an *Interglacial* stage: *Fossiliferous limestones* & calcareous sandstones, emerged *Coral Reefs*				
Pleistocene / Tertiary	Pliocene	Pliocene or early Pleistocene *White Mountain series* Lacustrine cherts, limestones and marls 370 feet	*Pliocene and/or early Pleistocene* Ferruginous and sometimes aluminous hardpan formations known as "laterite" or "duricrust" ?Fortescue River beds (lacustrine)	?Lacustrine sands of Collie basin		
Tertiary	Miocene		Limestones with *Flosculinella* and *Trilline* Limestones with *Lepidocycline murrayana* and *L. verbeeki* *Aturia* beds of Kennedy Range	*Plantagenet series* Siltstones, sandstones, spongolites 200 ft.	*Eucla limestone* of Nullarbor Plain (Possibly partly Oligocene) 900 ft.	*Norseman limestones* and *Lake Cowan spongolites* (up to 50 ft.)
Tertiary	Oligocene		Limestones with *Lepidocycline dilatata* and *L. papuanensis*			
Tertiary	Eocene		*Discocyclina* limestone	Foraminiferal sands and clays in bores below Perth to 770 ft. below sea level		
Cretaceous	Upper		CARDABIA RANGE *Cardabia series* 900 ft. Bryozoa limestone Greensand with *Eubaculites*, etc., Chalk, chalky clay, claystones	MURCHISON RIVER *Murchison House series* 750 ft. Second Gully shale Toolonga chalk Alinga beds Thirindine shale Butte sandstone Tumblagooda sandstone SOUTH-WEST COASTAL PLAIN *Gingin series* Upper greensand Chalk Lower greensand 230 ft.		*Wilkinson Range series* Sandstones, conglomerates, tillites, 200 ft + (possibly of Permian age)
Cretaceous	Lower		*Winning series* 1,100 ft. Siltstones and chert Green gypseous shale Glauconitic sandstone	?Bullsbrook plant beds	Sandstones and shales with *Maccoyella* and *Aucella hughendensis* (in bores only) 1,000 ft.	
Jurassic	Upper	*Derby series* (300 ft) Sandstones with *Thinnfeldia*, *Otozamites*, etc. *Buchia–Belemnopsis* sandstones 500 ft + (in bores only)		*Isoetites* beds of Gingin		
Jurassic	Middle		*Algal beds* of Minilya River (with *Parachaetetes*) 20 ft.	*Newmarracarra series* Sandstones and shales		
Jurassic	Lower			*Otozamites sandstones* of Geraldton district and Coastal Plain, 1,000 ft +		
Triassic				*?Donnybrook sandstone* (possibly younger)		

	WEST KIMBERLEY	EAST KIMBERLEY	MINILYA RIVER	GASCOYNE RIVER
Upper?	*Erskine series* 350 ft Estuarine, plant bearing			

System	Series	West Kimberley	East Kimberley	Minilya River	Gascoyne River	Greenough and Irwin Rivers	Collie		Eastern
Triassic						(possibly younger)			
Permian	Upper ?	*Erskine series* 350 ft Estuarine, plant bearing	? Thick conglomerates and sandstones (insufficiently investigated) ?						
	Middle (Kungurian + Artinskian)	*Upper Ferruginous series* Fusulinid beds Richly fossiliferous sandstones 1,400 ft *Noonkanbah series* Richly fossiliferous limestones and shales 1,200 ft *Lower Ferruginous series* Conglomerates, sandstones, shales (*Glossopteris* flora) 2,200 ft. *Nura Nura limestone*, marine glacial 20 ft		*Wandagee Hill series* Sandstones 700 ft. *Wandagee series* Sandstones and shales 2,350 ft. (d) *Linoproductus* stage (c) *Schizodus* stage (b) *Calceolispongia* stage (a) *Lingula* stage *Cundlego series* Sandstones and shales 1,000 ft. *Bulgadoo shales* 2,200 ft. *Wooramel sandstone* 180 ft *Callytharra series* Limestones and shales 675 ft.	*Kennedy sandstone* 500 ft. *Byro series* 2,500 ft.	GREENOUGH AND IRWIN RIVERS Sandstones and shales *Irwin River* and *Eradu* coal measures (*Glossopteris* flora) 140 ft. + *Fossil Cliff limestone* 190 ft.	*Collie & Wilga* coal measures (*Glossopteris* flora) 2,000 ft.		*? Paterson Range series* Permian rocks extend from the West Kimberley into this division (insufficiently investigated) Wilkinson Range series possibly of this age (see under Cretaceous)
	Lower (Sakmarian)	*Grant Range series* *Poole Range series* Sandstones, conglomerates, tillites 2,000 ft. +		*Lyons River series* Sandstones, conglomerates, tillites, 2,000–2,500 ft.		Shales and mudstones with *Metalegoceras jacksoni*, 2,500 ft, Tillites 200 ft. +			
Carboniferous			Bryozoan limestone of Burt Range 350 ft.						
Devonian	Upper	Stromatoporoid limestones of Napier Ra. Oscar Ra etc. apt 5,000 ft *Productella* limestone *Sporadoceras* beds *Cheiloceras* beds *Manticoceras* beds	Sandstones with worm-burrows 1,000 ft Limestone—shale series very fossiliferous 4000 ft *Cockatoo sandstones* & conglomerates (*Lepidodendron*) 4,800 ft.						
	Middle	*Atrypa* limestone *Amphipora* limestone							
	Lower								
Silurian									
Ordovician									Quartzites and sandstones of James Range etc. (Extension of Larapintine series from Central Australia)
Cambrian	Upper ? Middle		*Mt. Elder series* Sandstones 2,000 ft +						
	Lower		*Negri series* Shales, limestones 1,000 ft. *Xystridurus* zone *Girvanella* limestone *Redlichia* zone *Basalt* 2,000 ft	? Fossiliferous sandstones overlying Nullagine series					



they are inclined to be repeated many times in the same state (Round Hill, Table Hill, Mt. Remarkable).

CAMBRIAN[5]

DISTRIBUTION

Rocks of proved Cambrian age are known only in the extreme northeast of the state, where they form the western end of a belt of Cambrian rocks that may extend intermittently across the Northern Territory into western Queensland. On Western Australian territory the Cambrian rocks extend as a narrow belt along the boundary between approximately 18° 30′ and 16° 15′ S. Lat., reaching westward from the boundary for 15 to 75 miles.

This entire area is covered by a sheet of basalt, about 2,000 feet thick, which has an irregular surface forming ridges and depressions. In the depressions sedimentary strata which once covered the basalt everywhere have been preserved. These sediment-filled depressions have now generally been eroded down to a level below that of the basalt rises and are known locally as "Downs" country. The margins of some of these depressions are steep monoclinal flexures and the basal limestones of the sedimentary series occupy in many places a steeply dipping, or vertical position. Since they are more resistant to erosion than both the overlying shales and the underlying top layers of the basalt (which are mostly agglomerates and vesicular flows), they form in many places almost vertical "limestone walls," 30–50 feet high. These striking physiographical features have puzzled many earlier observers. (Fig. 2, insert of photographs.)

The main structural features in the arrangement of the Cambrian sediments are from north to south:

(1) Argyle basin, about 25 miles long and 7 miles wide, with the long axis striking northeast-southwest, and faulted along its northwest side against pre-Cambrian and other rocks;

(2) Rosewood basin, about 40 miles long and 11 miles wide, approximately parallel with the former; and

(3) Hardman basin, 75 miles long and 35 miles wide, which is subdivided by the Kelly Creek anticline into a smaller basin in the north (Mt. Elder basin) and a larger basin in the south (Dixon Range basin). This basin is truncated near its southwestern end by a major fault zone, the Hardman fault.

The stratigraphy is most complete in the Hardman basin which is therefore considered first. Only a small thickness of strata is preserved in the northeastern part of the Rosewood basin (the only part so far investigated) and the succession in the Argyle basin is somewhat different from that in the more southern area.

[5] The areas now known to be underlain by rocks of Lower and Middle Cambrian age were shown as "Carboniferous" on earlier maps to about 1923. Subsequently, they were mapped as "Upper Cambrian" by Wade, and by some they were regarded as Middle Cambrian. In the other hand, some maps published after 1923 show large areas of "Lower Cambrian" in the East Kimberley which include non-fossiliferous quartzites and sandstones underlying Lower Cambrian basalts and are therefore undoubtedly pre-Cambrian in age.

It is possible that Cambrian or other Lower Paleozoic rocks will be found to occur on the Western Australian Plateau, where they may be associated with the pre-Cambrian Nullagine series. West of Lake Carnegie (about 23° 20′ S. Lat., 122° 20′ E. Long.), an obscure impression of an edrioasteroid has been reported by Chapman from limestones interbedded with shales and sandstones, believed to

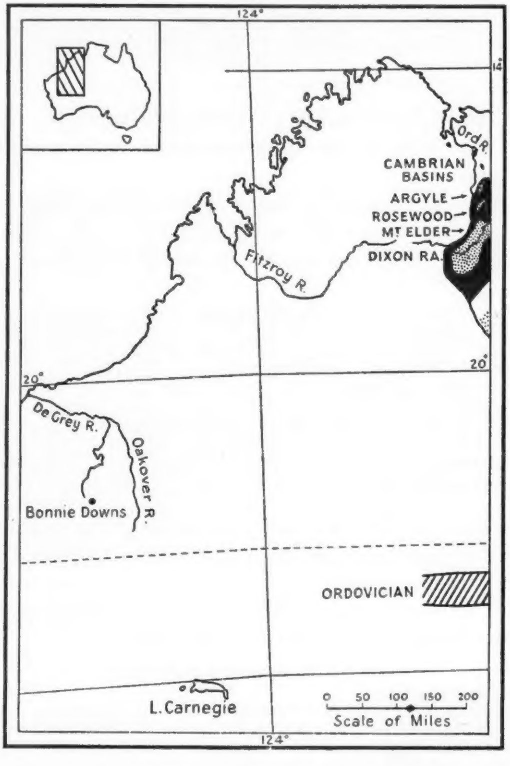


FIG. 1.—Distribution of Cambrian and Ordovician rocks. ***Black:*** basalt; ***stippled:*** sediments; ***oblique ruling:*** Ordovician. Bonnie Downs and Lake Carnegie are localities from which doubtful fossil remains of early Paleozoic age have been reported.

be Nullagine in age. Also, in 1944, fragmentary impressions of a gastropod and a merostome crustacean were found on Bonnie Downs Station, in sandstone mapped as Nullagine about 35 miles south of Nullagine, and about 275 miles northwest of the aforementioned locality.

SUCCESSION

The Cambrian sequence consists of basalt flows and agglomerates at the

base, overlain by sediments of Lower and Middle Cambrian, and perhaps Upper Cambrian age. The general succession is as follows:[6]

Middle Cambrian	MT. ELDER SERIES Red shales, overlain by brick-red sandstones, cross-bedded near top Thickness (approx.) 2,000 feet
Lower Cambrian	NEGRI SERIES Shales and limestones. Thickness 850–1,000 ft.
	Basalt Thickness (approx.) 2,000 ft.

The basalts rest unconformably on pre-Cambrian rocks. As described by Edwards[7] they range from olivine- to quartz-basalts and are of the tholeiitic or plateau-basalt type.

Throughout most of the area the base of the overlying Negri series is formed by a massive, hard limestone which is up to 50 feet thick. This is followed by alternating shales and limestones and the generalized section of the Negri series is as follows.

NEGRI SERIES

	Feet
Limestone	10
Calcareous shale	235
Limestone with *Girvanella*	10– 20
Calcareous shales ....approx.	120
Limestone, lower part cherty, upper part pure, with *Redlichia forresti*	55
Calcareous shales	150–525
Basal limestone (cherty)	40– 50

The four limestone beds of this series are ordinarily well defined in the field. On the Western Australian side of the boundary the uppermost and the lowermost limestones are everywhere non-fossiliferous, but a few miles beyond the boundary, at Mt. Panton in the Northern Territory, the uppermost shales and limestones are fossiliferous and the section is here as follows.

NEGRI SERIES AT MT. PANTON

	Feet
Limestone with *Girvanella* and *Biconulites*	10
Alternating shales and limestones with *Redlichia* and *Xystridura*, very fossiliferous	125
Limestone with *Girvanella* and *Biconulites*	10
Red and gray shales	135

Mt. Panton rises from a plain which is partly underlain by limestones which seem to correspond with the limestones with *Redlichia forresti* of Western Australia. The higher shales and limestones with *Xystridura* and *Redlichia* correspond with non-fossiliferous shales and limestones on the Western Australian side of the

[6] C. Teichert and R. S. Matheson, "Geological Reconnaissance in the Eastern Portion of the Kimberley Division, Western Australia," *Geol. Survey Western Australia, Ann. Rept. 1945*. Perth (1946).

[7] A. B. Edwards and E. de C. Clarke, "Some Cambrian Basalts from the East Kimberley, Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 26 (1939–40), pp. 77–94. 1940.

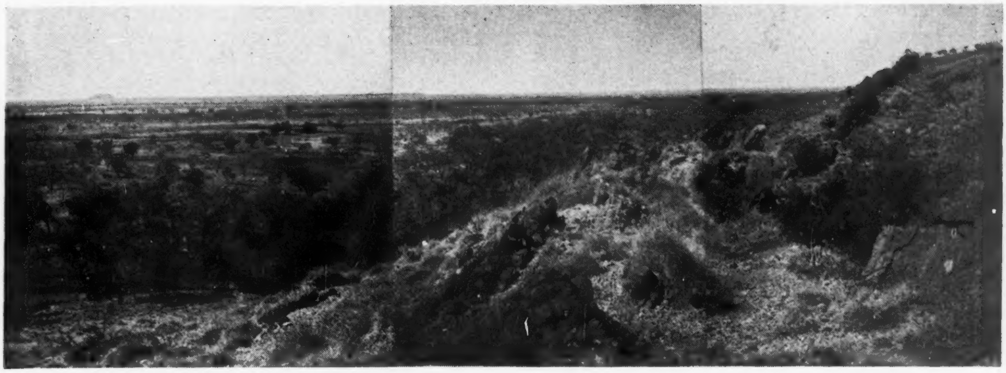


FIG. 2.—Vicinity of Mt. Napier; eastward view overlooking the flat with Mt. Panton toward northeast. Rocks in right foreground are basalt, followed by basal Cambrian limestone steeply dipping north; low country is occupied by shales and limestones of Negri series; Mt. Panton in distance on left. Although this country is just outside Western Australia in the Northern Territory, the view is typical of basalt and sedimentary topography in East Kimberley Division.

FIG. 4.—Interior of Burt Range, showing an anticline in Devonian sandstones and limestones, seen from south part of range, looking north. Steep cliff on right-hand side consists entirely of Permian (?) conglomerates.

FIG. 5.—Solid stromatoporoid reef weathered out of Upper Devonian shales and sandstones. Southeast part of Rough Range, West Kimberley Division.

FIG. 6.—Upper Devonian conglomerate in bed of tributary of Mt. Pierre Creek, between Mt. Pierre Creek and Trig. Station J8.

FIG. 7.—Southeast part of Rough Range with southwest-dipping goniatite beds of Upper Devonian, seen from southeast; foreground covered with residual boulders of conglomerate facies of Upper Devonian stage II.

FIG. 9.—Central part of Burt Range. Lower part of slope consists of Carboniferous limestones, overlain by Permian (?) sandstones and conglomerates. In foreground, Devonian sandstones.

FIG. 11.—Permian sandstones, dipping south, near Gogo Homestead, West Kimberley Division.

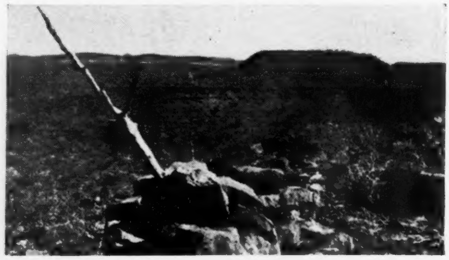


FIG. 12.—Calcareous shales and limestones of Callytharra series. Near Trig. Station K52 in north continuation of Kennedy Range, between Williambury and Middalya Homesteads, North-West Division.

FIG. 13.—Aerial view of country south of Minilya River, at about 114½° E. Long. In center of picture is Wandagee Hill; at left (east) of it and in foreground, sandstones and shales of Wandagee series; in right foreground, syncline in upper Wandagee series (beds with *Paragastrioceras*, *Propinacoceras*, *Helicoprion*, and rich invertebrate fauna)—this country is shown in Fig. 14. White cliffs in distance are shales of Cretaceous, resting (probably unconformably) on Permian. Scrub-covered country on right-hand side is underlain by greensands and shales of Cretaceous, separated from Permian by a fault. (Photo by permission of Department of the Army.)

FIG. 14.—Permian sandstones in North-West Division. In foreground, richly fossiliferous sandstones of Wandagee series; in distance, Wandagee Hill.

FIG. 15.—Mesa topography on Irwin River, South-West Division. Cliffs are formed by Permian shales and sandstones.

FIG. 16.—Open cut at Stockton Mine, Collie coal field. Two seams of coal, separated by shales and sandstones with *Glossopteris* flora.

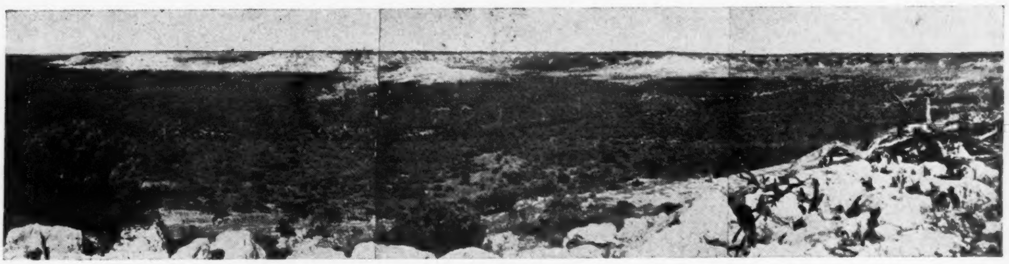


FIG. 19.—Cliffs of Cretaceous rocks on north side of Murchison River, looking southwest from point about 12 miles from shore of Indian Ocean. Upper part of scarp is formed by chalk; lower level is top of Tumblagooda sandstone.

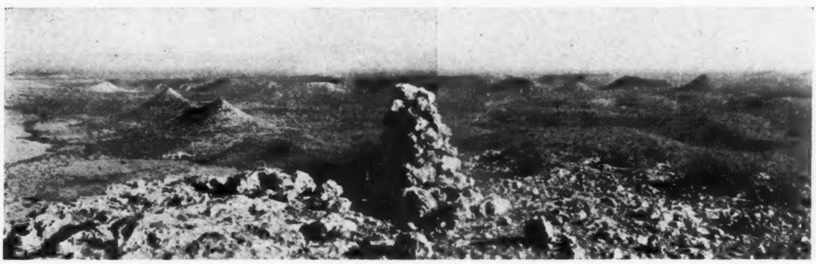


FIG. 20.—Cretaceous shales and sandstones of Cardabia Ranges, looking north from Remarkable Hill.

FIG. 22.—Thin veneer of fossiliferous Miocene limestone on floor of Lake Cowan, near the "Peninsula," 12 miles north of Norseman. High ground in distance is pre-Cambrian of Western Australian shield.

FIG. 23.—Tertiary limestones of North-West Cape Range. Yardie Creek.

FIG. 24.—Converging anticlines in Tertiary limestones near mouth of Minilya River. (Photo by permission of Department of the Army.)

FIG. 25.—White Mountains, East Kimberley Division. In foreground, Pliocene marls and limestones, capped by chert, dipping 25° NE. In distance, Cambrian sandstones at foot of hill, overlain disconformably by almost horizontal Pliocene rocks, capped by chert with *Planorbis*.

FIG. 26.—Emerged coral reef, Pelsart Island, Houtman's Abrolhos. Limestone platform is about 8 feet above mean sea-level; it is overlain by 2–3 feet of non-coralline limestone (foreground) and bears a beach ridge of coral shingle of mid-Recent age, visible on platform in distance.

boundary. *Xystridura* is a trilobite previously described from Queensland where it is almost restricted to the *Dinesus* zone of the upper Templeton series of Middle Cambrian age, but in the Mt. Panton section the genus is associated with one or two large new species of *Redlichia* so that the beds must be classified as Lower Cambrian.

The faunal succession of the Lower Cambrian Negri series of Western Australia and the adjacent Northern Territory is therefore as follows.

Upper subzone with *Girvanella*
Subzone with *Xystridura* and *Redlichia*
Lower subzone with *Girvanella*
Subzone with *Redlichia forresti*

In the Argyle basin, near the northern end of the Cambrian belt, the succession of strata in the Negri series is somewhat different. The basal limestone is missing and the basalt is overlain by shales which may be as much as 1,000 feet thick. These are followed by a series of alternating limestones and shales which, however, contain only one fossiliferous horizon with *Girvanella*, *Biconulites*, and a small species of *Redlichia*. Other limestone beds are non-fossiliferous. From its position in the section, it appears that the *Girvanella* limestone of the Argyle basin probably has to be correlated with the lower *Girvanella* limestone of the southern area and is thus stratigraphically below the *Xystridura-Redlichia* subzone.

The Mt. Elder series is as yet incompletely known. In the vicinity of Mt. Elder it consists of 650 feet of basal red shales, overlain by about 1,300 feet of sandstones with characteristic brick-red color. Throughout most of their thickness these sandstones are well bedded, but the uppermost 100 feet or so are cross-bedded and toward the top the red color gradually changes into pink and finally white. There is probably a greater thickness of this series west of the Ord River, particularly in the Dixon Range, and from the scanty information available it seems that cross-bedded sandstones are here more prominent. It may be that the Mt. Elder series west of the Ord is thicker and that a greater part of the upper cross-bedded part is preserved there, which is mostly eroded away in the vicinity of Mt. Elder.

The Mt. Elder series is conformable with the Negri series and there is no sudden change in the character of the sediments. Since the highest beds of the Negri series are late Lower Cambrian in age, much of the Mt. Elder series must be Middle Cambrian, although sedimentation might have continued into the Upper Cambrian.

In widely distant places, such as Behn River, Negri River, and Elvire River, it was observed that immediately below its junction with the Negri series the basalt is invariably vesicular and in places agglomeratic. These softer rocks would have been easily eroded, if the surface of the basalt had been exposed for some time, and it must therefore be assumed that no appreciable time interval elapsed between the cessation of volcanic activity and the beginning of the formation of

the Negri series. It is therefore reasonable to assume that the basalts are early to middle Lower Cambrian in age.

Soon after its formation the basalt must have been submerged below a moderately deep sea in which the shales and limestones of the Negri series were deposited. Gradually the sea became shallower, and sandstones were laid down. Cross-bedding in the upper part of the sandstone series indicates further shallowing of the sea, preceding the final drying-up of the area some time in the late Middle or Upper Cambrian.

ORDOVICIAN[8]

A number of low ranges (Walter James Range, Robert Range, and others) near the State boundary at about 24° S. Lat. consist of sandstones and quartzites which are possibly an extension of the Ordovician Larapintine series of the Amadeus Sunkland in Central Australia.[9]

The rocks are folded, but their thickness is not known and no fossils have been found, so that the correlation with Central Australian rocks rests on similarities of lithology only.

How far these rocks extend into Western Australia and what area they may cover is at present unknown. If the present opinion as to the age of these beds is correct, a sedimentary series measuring several thousand feet thickness may be expected to be present in that part of the state, for the Ordovician of Central Australia is as much as 6,000 feet thick.

SILURIAN[10]

No Silurian rocks are known in Western Australia.

DEVONIAN

DISTRIBUTION

Devonian rocks are not known in Western Australia outside the Kimberley Division. Here they occur in two widely separate areas.

1. The East Kimberley[11] area is close to the Northern Territory boundary, north of 16° S. Lat. At present strata of Devonian age are known between the Ord River and the Northern Territory boundary and between approximately 15°

[8] The Nullagine series and related beds, now considered to be pre-Cambrian in age, have been classified by some as Ordovician.

[9] H. A. Ellis, "Report on Some Observations Made on a Journey from Alice Springs, N. T., to the Country North of the Rawlinson Ranges, W. A. &c.," *Geol. Survey Western Australia, Ann. Progr. Rept. 1936* (1937), p. 25.

[10] In the past, quartzites of the Stirling Range in the South-West Division were sometimes mapped as "Silurian," but are now regarded as pre-Cambrian. Metamorphic pre-Cambrian rocks of the East Kimberley Division were once classified as "Cambro-Silurian" or "Silurian," but this notion has been abandoned for the last 30 years or so.

[11] Many earlier maps of the East Kimberley Division, up to about 1924, show large areas of "Devonian" in country now known to consist of pre-Cambrian and Paleozoic rocks and which incidentally also include some rocks of Devonian age. The same areas were shown on other, more recent maps, as "Lower Cambrian," or as "Precambrian" without any new investigations having taken place. The first fossiliferous Devonian in the East Kimberley was discovered in 1941, but its full extent was not realized until 1945.

30′ and 16° S. Lat. The bulk of the Devonian rocks in this area occurs in a large basin-like structure which has its center in the Burt Range and part of which at least is in the Northern Territory where it has not yet been investigated. A minor occurrence of Devonian rocks is known from the valley of the Ord a few miles below Ivanhoe Homestead. It is probable that further Devonian outcrop areas are present west of the Northern Territory boundary north of 15° 30′ S. Lat., but this country is as yet geologically unexplored.

2. The West Kimberley area is a belt about 200 miles long and as much as 40 miles wide, extending from near the east side of King Sound (about 124° E.

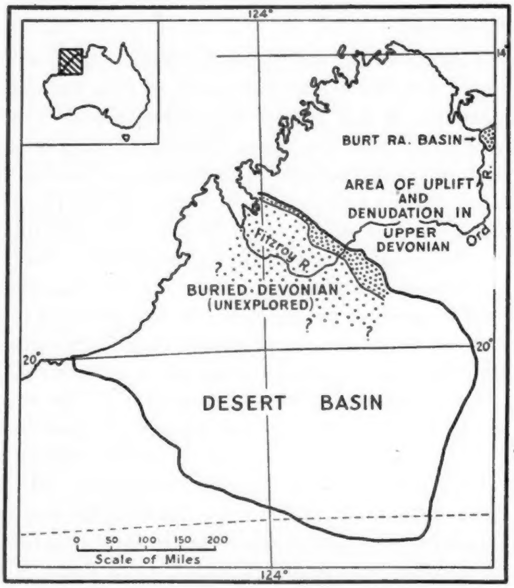


FIG. 3.—Distribution of Devonian rocks. *Dense stippling:* outcrop areas; *wide stippling:* buried Devonian.

Long., 17° S. Lat.) southeastward to the vicinity of the Margaret River and Christmas Creek (about 126° 10′ E. Long., 18° 35′ S. Lat.). This belt includes a number of low limestone ranges such as Napier Range, Oscar Range, Geikie Range, Rough Range, Bugle Range. It widens toward the southeast where it includes much flat and irregularly hilly country.

SUCCESSION

1. *East Kimberley.*[12]—The chief development of the Devonian in this part of the country is in the synclinal basin whose center is occupied by the Burt Range

[12] C. Teichert and R. S. Matheson, "Geological Reconnaissance in the Eastern Portion of the Kimberley Division, Western Australia," *Geol. Survey Western Australia, Ann. Progr. Rept. 1945.* Perth (1946).

and which for the present may be called Burt Range basin. (Fig. 4, insert of photographs.) The series begins here with a thick series of conglomerates and sandstones which pass upward into shales, calcareous sandstones, and limestones which in turn are followed by another sandstone series. These rocks occupy the flat or slightly hilly country for several miles west of the Burt Range as well as the first, or westernmost ridge of the Burt Range itself. The succession is here as follows.

	Feet
Upper sandstone series	1,000
Limestone series with interbedded shales and calcareous sandstones	4,000
Cockatoo sandstones and conglomerates	4,800
Total thickness	9,800

The Cockatoo sandstones and conglomerates rest on basalt which in one place was seen to be about 100 feet thick. The basalt in turn lies unconformably on pre-Cambrian quartzites. It is at present impossible to state whether or not this basalt is contemporaneous with the Lower Cambrian basalt of the Argyle basin and the other Cambrian basins farther south. Present indications are that in spite of its great similarity to the Cambrian basalt it may well be Devonian in age.

The Cockatoo sandstone series[13] itself begins with sandstones with interbedded conglomerates which contain quartzite pebbles. The sandstones are typically strongly cross-bedded; many of them are only loosely cemented and soft, and they tend to weather out in pinnacles and pedestal rocks; their color is mostly gray, but red sandstones occur among them. In general it is the lower part, approximately the lower 1,500 feet or so, which is more resistant to erosion and weathering. Conglomerates gradually disappear in the sequence and the coarse-grained sandstones give way to fine-grained sandstones some of which are cross-bedded and commonly very loosely cemented. Outcrops in this upper part of the Cockatoo series are therefore generally very poor. Mt. Cecil, however, on the western flank of the basin, only a few miles from the Ivanhoe-Argyle road is a dome structure formed of higher sandstones of the Cockatoo series in which imprints of *Lepidodendron* were found. The Mt. Cecil dome is traversed by a number of minor faults and silicification along the fault planes has provided a rigid lattice work around and between which the softer sandstones have been protected from erosion.

The Cockatoo sandstones pass gradually into the next following series which is characterized by an alternation of sandstones, shales, and an increasing number of limestones. The lowermost limestones, interbedded with calcareous, fine-grained sandstones, are non-fossiliferous, but, at several hundred feet higher, brachiopods occur and the limestones are increasingly fossiliferous. Very little collecting has so far been done, but the general impression derived in the field was

[13] The name is derived from Cockatoo Springs on the road from Ivanhoe to Argyle Homesteads, 26 miles from Ivanhoe. In this vicinity the weathering of the Devonian sandstone results in the formation of very sandy soil and this stretch of country is locally known as "Cockatoo sands." These sandstones were first noted by Wade in 1924, who referred them tentatively to the Upper Carboniferous.

that species of *Camarotoechia* and *Meristella* appear first. They are soon joined by small species of *Productella* and some limestone beds were found with characteristic *Camarotoechia-Productella* assemblages identical with those of the *Productella* limestone of the West Kimberley Division described in subsequent paragraphs. Still higher in the sequence new and larger species of *Productella* appear, accompanied by spiriferids, *Straparollus*-like gastropods, by nautiloids of the *Spyroceras*-type, and by a rich fauna of smaller brachiopods, as yet unidentified. Not only the limestone beds themselves, rarely more than 5 or 6 feet thick, but also the intercalated calcareous shales and sandstones are in places richly fossiliferous.

Toward the top of the limestone series, the intercalated sandstones become more coarse-grained and the larger productids disappear from the limestone assemblages, leaving only smaller brachiopods among which *Camarotoechia* is everywhere prominent. Thus, the passage to the Upper Sandstone series is very gradual. This series is fairly uniform throughout, well bedded, in many places with cross-bedding between the major bedding planes. A conspicuous feature are the many vertical burrows which are found at numerous depths. They vary greatly in size although all the burrows in the same bed are of the same order of magnitude. Larger burrows may be about 2 inches in diameter and may be as much as 10 inches long. They are easily recognizable by the darker staining of the sandstone material filling them. Tracks, probably worm tracks, were seen on some bedding places, though they do not seem to be common.

At present the writer is inclined to consider the entire series of rocks described in the preceding paragraphs as Upper Devonian. The lower part of the limestone series seems to correspond with the *Productella* limestone of the West Kimberley which has been correlated with Stage IV of the Upper Devonian standard section. The upper part of the limestone series is thus younger, most likely corresponding with Upper Devonian Stage V, and the Upper Sandstone series accordingly belongs to the closing stage of the Devonian period. The Cockatoo series must probably be correlated with the earlier Upper Devonian (Goniatite beds) of the West Kimberley Division. The end of the Middle Devonian was a time of uplift in an area east and northeast of the Fitzroy basin, probably mainly in the vicinity of the present Hall's Creek. Thick conglomerates and sandstones were deposited in the eastern part of the West Kimberley Division during early Upper Devonian time and it seems reasonable to assume that the Cockatoo sandstone series represents the detritus which was transported simultaneously northward from this uplift area.

The upper boundary of the Devonian in the Burt Range is as yet undefined as the actual contact with the overlying Carboniferous limestones has not been seen.

2. *West Kimberley.*—Although no detailed mapping of the Devonian outcrops in this area has as yet been done, the chief outlines of the stratigraphy can be stated with some degree of reliability. The belt of Devonian rocks as shown on maps of the state seems to take its beginning on the east side of King Sound, just

north of the mouth of the Meda River. From here it strikes first eastward and then bends into a southeastern direction. No details about this part of the outcrop area seem to be known and no geological features are discernible in this country from the air.

It is only a few miles northwest of the Alexandra River that the Devonian belt begins to form a distinct topographical feature: rough, weathered limestone outcrops begin to appear which, southeast of the Alexandra, become more prominent and form a low, very rugged limestone ridge known as Napier Range. Farther southeast follow ranges of a very similar lithological type: the Oscar Range and the Geikie Range. All along this belt the Devonian limestones are topographically very distinct. They overlie the pre-Cambrian metamorphics at the northeast and they dip southwestward below the Permian. Southeast of Geikie Range the Devonian belt widens and includes ranges, isolated hills, and level country: Needle Eye Rocks, Mount Pierre, Fossil Hill, Rough Range, Bugle Range, and others. This belt is dissected by the Margaret River and Mount Pierre Creek and extends southeastward as far as the Louisa River.

A great variety of facies is found among the Devonian rocks of this belt and the rock types range from conglomerates with boulders many feet in diameter on the one hand to pure reef limestones on the other. No Lower Devonian is present, but both Middle and Upper Devonian are well represented.[14]

The lithologic character of the Middle Devonian is very uniform over the entire area. The rocks are almost exclusively limestone with only a few feet of grit and sandstone where the overlap onto the basal pre-Cambrian rocks can be seen. In some places in the Rough Range, beds of limestone containing angular fairly fresh fragments of feldspar were seen a short distance above the base of the sedimentary series. For the time being, the Middle Devonian limestones have been divided into two sections: a lower *Amphipora* limestone, and an upper *Atrypa* limestone. The Middle Devonian begins locally with non-fossiliferous limestones, but in places *Amphipora* limestones rest directly on the pre-Cambrian basement. This part of the sequence is very monotonous, *Amphipora ramosa*, a small branching stromatoporoid, filling the limestones in untold numbers. Although *Amphipora* biostromes make up the section for a considerable vertical extent, other fossiliferous layers are in places intercalated. Some of them may be described as *Thamnopora* biostromes, others as *Stachyodes* biostromes, and so forth. Certain other species, notably *Prismatophyllum* and the gastropod *Murchisonia*, are restricted to certain layers without, however, forming definite biostromes.

Higher in the section the biostrome facies is replaced by typical bioherms. Small reefs of concentrically built stromatoporoids of the *Actinostroma* type begin to appear and shelly fossils become more numerous. Since *Atrypa* is an ubiquitous

[14] C. Teichert, "The Devonian of Western Australia. A Preliminary Review," *Amer. Jour. Sci.*, Vol. 241 (1943), pp. 69–94, 167–84. (With complete bibliography on the Devonian of the West Kimberley.)

member of the faunas of these higher Middle Devonian limestones, the name *Atrypa* limestone has been given to this part of the section.

The thickness of the Middle Devonian has been measured only in one or two places where it is approximately 2,000 feet. In the northwestern limestone belt (Napier and Oscar Ranges) the entire Devonian is represented by a uniform limestone series and Middle and Upper Devonian have not yet been sharply differentiated everywhere. In general the Middle Devonian limestones seem to become more fossiliferous toward the southeast, and in the Rough Range, near Mount Pierre Creek, and in the ranges and on the plains in that general area the *Atrypa* limestone is in places very fossiliferous and contains a great variety of brachiopods which include *Leptaena Rhipidomella, Schizophoria, Spirifer, Ambocoelia, Camarotoechia, Uncinulus, Hypothyridina,* and *Pugnax.* In addition, pelecypods, gastropods, and cephalopods may occur. In the bioherm facies corals are commonly found mixed with the prevailing stromatoporoids.

In the Upper Devonian the diversity of facies is very much greater. As has already been stated, in the Napier-Oscar-Geikie Range belt both Upper and Middle Devonian are represented by limestones, the Upper Devonian being characterized by a preponderance of reef limestones. In this part of the sequence individual stromatoporoid reefs attain considerable dimensions and may be 50 and 60 feet in height and several hundred feet in length, but hardly ever are any other fossils associated with them, with the exception of a few species of large pelecypods and gastropods which may occur in some beds.

The top of this limestone series is formed by brachiopod limestones in which *Productella* and *Camarotoechia* are very abundant. The total thickness of the Middle and Upper Devonian limestone series does not seem to exceed 5,000 feet.

Of greater stratigraphical and lithological interest is the southeastern area of Devonian rocks where an intricate pattern of interfingering facies is present, of which so far only the bare outlines are known.

Of considerable stratigraphical and paleogeographical importance is the goniatite facies which is now known to be distributed over considerable areas in the vicinity of Mt. Pierre as well as farther south in the southeastern part of Rough Range and on the plains and in the hills between Rough Range and the upper course of Mount Pierre Creek toward Mt. Pierre Well. These rocks are mostly red and gray calcareous sandstones and shales (typical redbed facies) in which goniatites occur in many places in great abundance. Other fossils, particularly sponges, corals, and brachiopods, are by no means absent, and along certain belts small stromatoporoid reefs are intercalated. In other places these beds grade into pure brachiopod shales or into shales with calcareous fossiliferous concretions.

Toward the east the beds become increasingly conglomeratic and the hills between the Trigonometrical Stations J8 and J7 are thickly covered with a layer of residual boulders of these conglomerates. From the air it can be seen that these beds extend east as far as the Louisa River. (Fig. 7, insert of photographs.)

Thanks to the abundance of good index fossils in the redbed facies and locally also in the conglomerates, the task of their correlation was not particularly difficult and until it is possible to map individual rock units in greater detail the strata have been divided in a general way into four stages which correspond rather closely with the first four Upper Devonian stages (I–IV) of the Upper Devonian goniatite type section of Germany.

The earliest of these, Stage I, is characterized by the goniatite *Manticoceras*. It became first known from Bugle Gap[15] where redbeds with *Manticoceras* and *Beloceras* overlap Middle Devonian reef limestones. Associated with the goniatites are other fossils, including a unique trilobite fauna with *Cyrtosymbole*, *Pteroparia*, *Drevermannia*, *Chaunoproetus*, *Harpes*, and *Scutellum*.

The *Manticoceras* beds have only been studied in the field in a few places. Elsewhere they are represented by shales with calcareous concretions containing *Manticoceras*, *Koenenites*, and *Timanites*, pointing to a very slightly younger age than the redbed fauna previously mentioned.

Higher than the *Manticoceras* beds is a redbed series with a somewhat poorer fauna of goniatites, among which *Cheiloceras*, *Tornoceras*, and *Dimeroceras* are most prominent, non-cephalopod species being all but absent. At present this *Cheiloceras* fauna is known in the vicinity of Mount Pierre, in southeastern Rough Range, and in the hills southeast of the latter. Toward the east the calcareous sandstone facies grades into conglomerates interbedded with red sandstones, some of which contain goniatites. (Fig. 6, insert of photographs.)

The next higher series is characterized by the goniatite *Sporadoceras*. The associated faunas are very much richer and more varied than those of the preceding stratigraphical stages. In addition to goniatites which include *Tornoceras*, *Dimeroceras*, and *Pseudoclymenia*, and nautiloids (including *Wadeoceras*), there is a fair variety of brachiopods (*Rhipidomella*, *Spirifer*, *Pugnax*, *Productella*, *Meristella*, *Ambocoelia*, *Gypidula*, *Camarotoechia*, and others) and some corals and sponges. Locally small stromatoporoid reefs, commonly associated with a characteristic fauna of cephalopods, appear in these beds. (Fig. 5, insert of photographs.)

As in the case of the *Cheiloceras* beds, the typical redbed facies of the *Sporadoceras* beds passes southeastward into coarse-grained sandstones and conglomerates. The whole sequence of rocks is regarded as an equivalent of Upper Devonian Stage III of the German type section. Its thickness, as far as known at present, does not seem to exceed a few hundred feet.

The last member of the Upper Devonian is a limestone series as much as 200 feet thick which contains abundant brachiopods and has been termed *Productella* limestone. In addition to *Productella*, it contains many other brachiopods. Most abundant is *Camarotoechia*. The two genera together are in places rock-building. Other common brachiopods belong to *Schizophoria*, *Leptostrophia*, *Stropheodonta*, *Athyris*, *Meristella*, and *Pugnax*. Goniatites are absent from this limestone, but

[15] C. Teichert, "Upper Devonian Goniatite Succession of Western Australia," *Amer. Jour. Sci.*, Vol. 239 (1941), pp. 148–53.

some interesting clymenoids occur which seem to be related to *Platyclymenia*, *Cyrtoclymenia*, and *Laevigites*. The appearance of clymenoids in these beds suggests correlation of the *Productella* limestone with Upper Devonian Stage IV of Germany. The *Productella* limestone seems to be rather uniformly developed over the entire area. Small stromatoporoid reefs are scattered through it everywhere, but no major reefs were built during the time of its deposition. It marks the

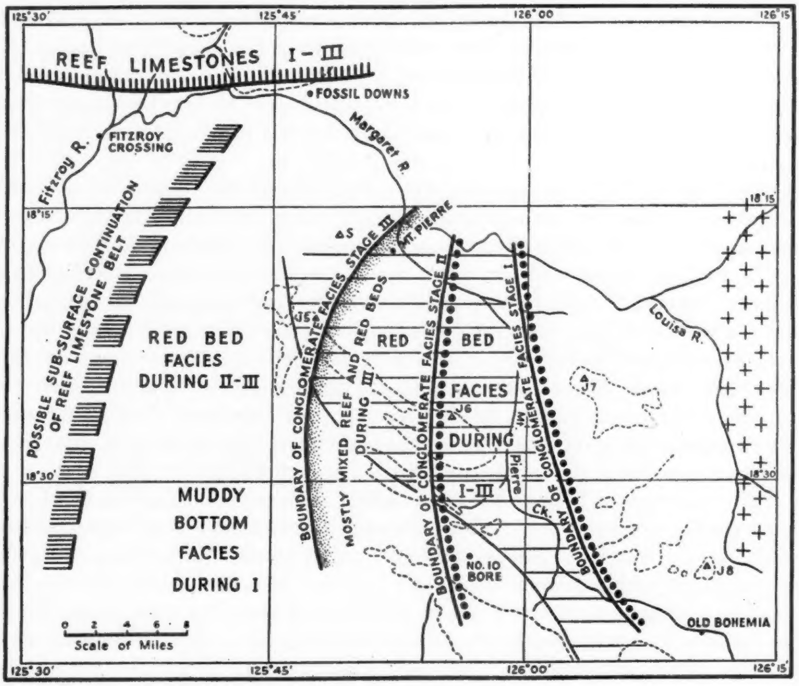


FIG. 8.—Facies map of Upper Devonian of Margaret River-Mount Pierre Creek area, West Kimberley Division.

closing stage of Devonian sedimentation of the West Kimberley. As previously mentioned, younger Devonian strata, corresponding with the higher Devonian beds elsewhere, are known in the East Kimberley Division close to the Northern Territory boundary.

DEVONIAN PALEOGEOGRAPHY OF WEST KIMBERLEY

Sedimentation began some time in the Middle Devonian probably in late Eifelian or early Givetian time; the sea transgressed over the pre-Cambrian in a

general easterly direction. The basement must have subsided at a rapid rate and the pre-Middle Devonian relief of the land on the whole must have been low, for there was little deposition of clastic material and very soon the formation of limestone commenced in the entire area. Thick limestone series were deposited largely by the activity of the small branching stromatoporoid *Amphipora ramosa*. Other stromatoporoids appear somewhat later in the Middle Devonian and begin to contribute materially to the limestones of the Middle and Upper Devonian in the northwestern area of distribution of Devonian rocks. Later in the Middle Devonian *Amphipora* disappeared completely from the entire area and richly fossiliferous brachiopod limestones were deposited. The coast at this time must have been far east of the present area of distribution of Middle Devonian rocks, for few indications of a Middle Devonian littoral facies have as yet been found.

A profound and very sudden change of conditions took place between the Middle and Upper Devonian. There must have been a sudden uplift of the mainland in the east which also affected the eastern reef belt of late Middle Devonian age, and which caused a retreat of the sea in a westerly direction. Reef-building activity ceased and massive conglomerates of pre-Cambrian rocks were piled on top of the Middle Devonian reefs. The conglomerates are found, in many places only as residual concentrates of quartzite boulders, in the country between Louisa River and Mount Pierre Creek in the vicinity of Trigonometrical Stations J7 and J8 where they rest on Middle Devonian reef limestones. Toward the west the conglomerates pass into a sandy and shaly facies though conglomerates are still present as far as the southeastern part of Rough Range.

The area west of about 123° 40′ E. Long. remains essentially unaffected by these changes. As mentioned before, all along the limestone belt of Napier, Oscar, and Geikie ranges, reef-building activities, mainly of stromatoporoids, continued without a major break from the Middle into the Upper Devonian. Between this "barrier reef" and the coast in the east, there was present a wide lagoon which was gradually being filled by clastic sediments during Upper Devonian time.[16]

The geological events that led to the profound changes in sedimentation in the southeast must have occurred suddenly at the beginning of Upper Devonian Stage I, for even during substage I they were already in operation and more stable conditions had been re-established. During the time of stages I, II, and III (*Manticoceras*, *Cheiloceras*, and *Sporadoceras* beds) the land in the east must have continued to rise slowly, because it furnished a constant flow of clastic material which was transported westward into the sea.

[16] Wade's "Gogo series," tentatively referred by that author to the Carboniferous, is the sandy facies of this Upper Devonian area of sedimentation. *Manticoceras*, *Koenenites*, and other Upper Devonian goniatites were found around No. 10 Bore on Gogo Station and in other areas shown as Gogo series on Wade's map. His "J8 beds," interpreted as Permian moraines, are the contemporaneous conglomeratic facies. *Cheiloceras* was found in pockets in such conglomerates in low hills southeast of the Rough Range, and in the southeastern part of Rough Range similar conglomerates were found interbedded with sandstones of Stage III of the Upper Devonian. See A. Wade, *Geological Map of the Kimberley Division of Western Australia* Canberra (1937).

Details of the history of the area during Stage I are as yet difficult to decipher, but during the later part of Stage II conglomeratic material was being transported much farther west than at the beginning of I. Between these conglomerates in the east and the barrier reef in the northwest there was a zone, at least 10 miles wide, probably with sandy bottom in the east and more calcareous muddy bottom in the west, where a fauna existed which was composed almost exclusively of goniatites and a few nautiloids. This may have been an almost completely enclosed basin with badly aerated bottom water which was unfavorable to benthonic life, but where nekto-benthonic cephalopods were able to exist.

During the time of Stage III (*Sporadoceras* beds) clastic material was transported still farther west than before, as is clearly indicated by the conditions in the southeastern part of Rough Range. Here sandy *Cheiloceras* beds are overlain by Lower *Sporadoceras* limestones with intercalated sandstones and conglomerates and the Upper *Sporadoceras* beds in this section seem to be predominantly sandy and conglomeratic. Still farther west the Lower *Sporadoceras* beds are represented by a bioherm facies and sandstones and shales predominate in the Upper *Sporadoceras* beds.

Living conditions must have been much improved for a rich fauna now invaded the lagoon. Close to the barrier reef in the west, conditions showed little change from the immediately preceding stages and goniatites dominated the scene, although there was gradually increasing immigration of other forms of life, mainly corals and brachiopods, into this zone. Farther inshore a belt of minor stromatoporoid reefs is recognizable between the clastic facies in the east and the goniatite redbeds in the west. Remnants of this belt are now exposed in southeastern Rough Range and at Mount Pierre.

It seems that the clastic sediments described were deposited in a large delta formation and the the bulk of the material was transported in a westerly direction from an area somewhere north of Trigonometrical Station J8 and probably east of the Louisa River. The barrier reef belt in the west may be expected to have continued south of the area in which the present outcrops of reef limestones are found. One may expect to find them under a thick cover of Permian sediments at least as far south as St. George's Range and the lower course of Christmas Creek, although the exact nature of the Devonian rocks below the Permian farther toward the center of the Desert basin could only be determined by borings.

Had conditions remained unchanged, the lagoon between the barrier reef and the coast would eventually have been filled by clastic sediments. As it was, however, the entire area subsided after the deposition of the *Sporadoceras* beds, the coast receded eastward and uniform conditions reminiscent of those of the Middle Devonian were restored over the entire area. Limestones and limestone conglomerates (*Productella* limestone) were deposited, reef-building activity was reduced to a small scale, and a rich fauna, mainly of brachiopods, moved in. This subsidence also affected the outer barrier where the reefs were brought so far below sea-level that they died.

CARBONIFEROUS[17]

DISTRIBUTION

At present Carboniferous rocks are known only in the Burt Range in the East Kimberley Division, about 15° 50′ S. Lat., close to the Northern Territory boundary. (Fig. 9, insert of photographs.)

SUCCESSION

Strata of this age are as yet very poorly known and at present only 350 feet of Bryozoa limestone can be referred to the Carboniferous with certainty. This limestone overlies the uppermost Devonian sandstones, though the contact between the two series has not yet been observed. The limestone is hard and dense and extremely fossiliferous. In addition to Bryozoa it contains some corals as well as brachiopods, but very little collecting has been done so far. The fossils include *Rhipidomella australis*, *Orthothetes*, *Camarotoechia*, *Dielasma*, in addition to spiriferids and productids.

PERMIAN[18,19]

DISTRIBUTION

Permian rocks are well exposed in Western Australia in a number of important areas, in order of size and importance as follows. (1) Desert basin in the Kimberley and Eastern Divisions. This is an area of unknown extent, possibly as much as 140,000 square miles, of which however, not more than 20,000 square miles have been geologically examined. (2) The North-West basin in the North-West Division, where an area of about 15,000 square miles extending from the vicinity of the Murchison River in the south to somewhat north of the Lyndon River in the north is underlain by Permian rocks. This is about 300 miles long and as much as 60 miles wide. (3) Various outcrop areas east of Geraldton and in the vicinity of Mingenew and the Irwin River, at the northern end of the South-West Coastal Plain between approximately 28° 30′ and 29° 20′ S. Lat. (4) The Collie-Wilga coal basin in the southwest (about $31\frac{1}{2}$° S. Lat.). (5) A recently discovered and as yet very insufficiently known area in the East Kimberley Division, near the Northern Territory boundary in the vicinity of 16° S. Lat.

A large area in the Central Division is covered by boulder beds and sandstones of uncertain age, known as Wilkinson Range series. These are here described in

[17] At one time or another all Paleozoic rocks of Western Australia have been mapped as Carboniferous and many maps have been published up to fairly recent times that show a greater or lesser extent of Carboniferous strata in various parts of the state. All these areas have eventually turned out to be either Cambrian, Devonian, or Permian. The first Carboniferous in Western Australia was discovered by R. S. Matheson and the writer in 1945.

[18] C. Teichert, "Upper Paleozoic of Western Australia: Correlation and Paleogeography," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25 (1941), pp. 371–415. (With almost complete bibliography.)

[19] Rocks of Permian age in Western Australia were at first regarded as Carboniferous. Since about 1910 it became more and more customary to refer to them as "Permo-Carboniferous," the implication being that the lower part of the system was Upper Carboniferous the higher part Permian. In 1931 Sir Edgeworth David proposed the name Kamilaroi System for the "Permo-Carboniferous" of eastern Australia. This term has never been widely used in Western Australia and in more recent years the Permian affinities of all the Western Australia faunas concerned have been recognized.

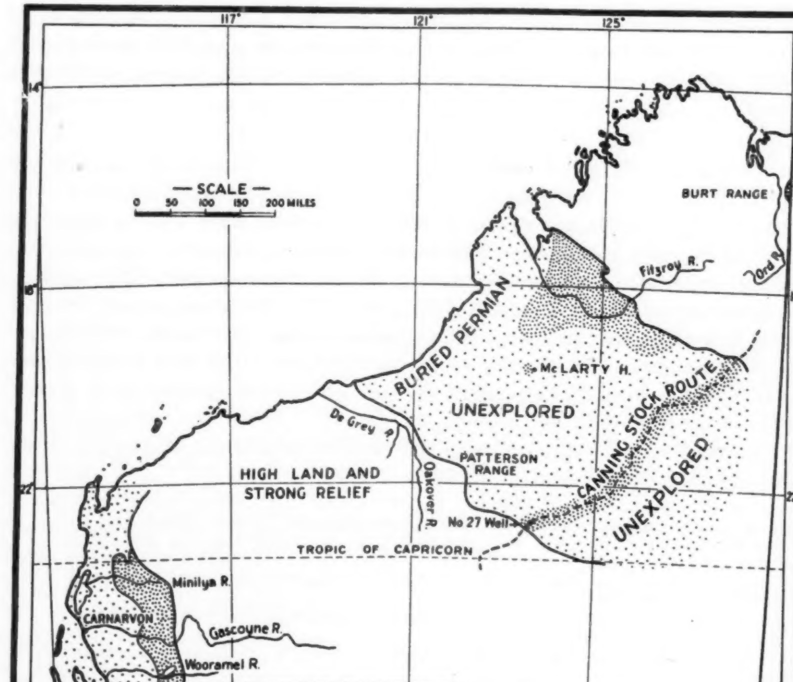


FIG. 10.—Distribution of Permian rocks. *Dense stippling:* outcrop area; *wide stippling:* buried Permian.

the chapter on the Cretaceous, although they might conceivably be Permian as advocated by some authors. Proof of their Permian age would of course greatly change our ideas of the Permian paleogeography of the interior of Western Australia.

SUCCESSION

(1) *Desert basin.*—The greater part of the Desert basin is geologically unexplored, but near its northern margin the stratigraphy has been studied in some detail. This part of the basin is traversed by the Fitzroy River and its tributaries which is the only major surface drainage system in the basin. The remaining 120,000 square miles are for all practical purposes *terra incognita.* The southern margin of the basin has been visited by geologists in a few places and two geologists have traversed the eastern half of the basin along the Canning Stock Route, but no attempt at a systematic survey of any part of this area has ever been made. The following account, therefore, deals almost exclusively with the stratigraphy of the Fitzroy River area.

A somewhat generalized table of the Permian sequence in this area is as follows (according to Wade).

	Feet
Erskine series. Estuarine conglomerates, grits, sandstones, and shales with plants	350
Upper Ferruginous series. Clays, grits, sandstones, mostly limonitized, with rich marine fauna	1,400
Nooncanbah series. Clays, shales, with calcareous beds, many of them passing into sandstone. Rich marine fauna	1,200
Lower Ferruginous series. Coarse, dark grits and conglomerates, sandy shales and flags, mostly heavily limonitized. Rich flora	2,000
Nura Nura limestone. Gray, sandy limestone with fossiliferous erratic boulders, arenaceous shales	20
Grant Range series. Sandstones, grits, arkoses, conglomerates, containing pebble bands, and in places larger boulders. Boulder clay and tillites. Clayey sandstones. Fossil wood	2,300
Kungangie series of Christmas Creek area. Fine-grained sandstones and clayey sandstones, coarse red grits, sandy shales, and cherts, probably also tillites and boulder clay. Fossil wood	2,000

In the Poole Range, southwest of Christmas Creek (18° 50′ S. Lat., 125° 45′ E. Long.), there is a fine series of boulder clays and tillite, known as Willanyie beds, which contain abundant ice-scratched, faceted, and polished boulders. This series may be more than 1,000 feet thick, and it may be the equivalent of the Grant Range series which occurs principally along the main valley of the Fitzroy.

All these lower, clastic, series seem to be very much alike and it seems that their proper correlation in the various parts of the area has not yet been fully established. The Grant Range, Kungangie, and Willanyie beds may all be contemporaneous.

There can, however, be little doubt as to the presence everywhere in this area of sediments of glacial origin, probably everywhere in excess of 1,000 feet, and possibly several thousand feet thick. It may be expected that the thickness of these lower beds is somewhat variable and it is, therefore, difficult to give a reliable estimate of the thickness of the entire Permian sequence. According to Wade, it may be between 7,500 and 8,000 feet. A series of conglomerates east of

the main area of distribution of the Permian rocks ("J8 beds," because they occur in the vicinity of Trigonometrical Station J8), formerly believed to be Permian in age, has turned out to be Upper Devonian.

The Nura Nura limestone is of great interest, because it is the lowest horizon with marine fossils in this sequence. It is fairly fossiliferous (chiefly brachiopods and bryozoa), though most fossils are as yet unidentified. Near the top there is a layer with limonitized fossils which include *Metalegoceras clarkei* and *Thallassoceras wadei*, indicating an age not younger than Artinskian.

The Lower Ferruginous series contains a flora of *Glossopteris*, *Vertebraria*, *Noeggerathiopsis*, *Lepidodendron*, and *Bothrodendron*. It is lithologically very uniform throughout its entire thickness. (Fig. 11, insert of photographs.)

The Nooncanbah series is extremely fossiliferous. Bryozoa and brachiopods are the most prominent groups, although corals and crinoids are also represented. Among the brachiopods are large productids and spiriferids as well as many smaller genera (*Strophalosia*, *Cleiothyridina*, *et al.*).

The Upper Ferruginous series (also known as Liveringa series) is essentially characterized by the presence of brachiopods and pelecypods which include species of *Streptorhynchus*, *Cleiothyridina*, *Aulosteges*, *Taeniothaerus*, *Linoproductus*, *Waagenoconcha*, *Spirifer*, *Strutchburia*, *Cardiomorpha*, *Schizodus*, and the Timor genus *Atomodesma*. The gastropods include large pleurotomarids, a large *Bellerophon*, and *Conularia*. Near the top of the series fusulinids (*Verbeekina* and *Neoschwagerina*) have been found. These seem to be the highest marine Permian beds in the Fitzroy River area.

The sandstones of the Erskine series are rich in plant fragments but poor in identifiable remains. *Lepidodendron*, *Cordaites*, and *Phyllotheca* have been doubtfully determined from this series.

Whereas, as has been pointed out already, the intra-basin correlation of the lower, glacial series is as yet somewhat unsatisfactory, due, of course, chiefly to the absence of fossils in these older beds, the sediments from the Lower Ferruginous series, to and including the Erskine, seem to be more evenly distributed over the entire area and there seem to be fewer changes in facies. However, no paleontological zoning has as yet been attempted in the marine section of the sequence and detailed correlation of many occurrences is, therefore, difficult.

The Permian rocks of the Fitzroy area are slightly folded, forming broad anticlines, domes, and synclines. Toward the south they can be seen to continue into the Desert basin, but the full extent of the outcrops in this direction has not yet been mapped.

In the western interior of the basin Permian fossils seem to occur in the vicinity of the McLarty Hills (123° 30′ E. Long., 19° 40′ S. Lat.).[20]

A few observations are available from the southwestern margin of the basin, where sandstones and grits are reported from the Paterson Range (22° S. Lat.,

[20] F. G. Clapp, "A Few Observations on the Geology and Geography of North-West and Desert Basins, Western Australia," *Proc. Linn. Soc. New South Wales*, Vol. 25 (1926), p. 54.

122° 15′ E. Long.). These have been regarded as Permian, although no fossil evidence is available. However, 100 miles southeast, at No. 27 Well on the Canning Stock Route, sandstones with undoubtedly Permian fossils have been found. This locality is only 10 miles from the southeastern margin of the Desert basin. From here the Canning Stock Route winds across the Desert basin in a northeasterly direction for about 400 miles.[21] Along much of this route flat-lying sandstones have been observed but no fossils have been found.

About 75 miles northwest of the Paterson Range a tillite occurrence has been reported near Braeside Station. This may well be Permian in age. Nearby, sediments, mostly limestones, are known to occur in the valley of the Oakover River and although they have been mostly referred to younger periods, they may be Paleozoic.

(2) *Northwest basin.*—Although no doubt Permian rocks underlie the entire Northwest basin, outcrops are restricted to an area of about 15,000 square miles, occupying approximately the eastern half of the surface of the basin. The extent and configuration of this area is now fairly well known, but detailed stratigraphical investigations have been made in very few spots only. In the past it has been attempted to apply one and the same stratigraphical nomenclature to the rocks in all parts of the basin, but as more details become available, it will become obvious that considerable lateral changes in facies and thickness of the strata exist and a multiple stratigraphical terminology will ultimately have to be developed.

The best known section is at present that along and in the vicinity of the Minilya River (approx. 24° S. Lat.)[22] where, however, the lower part of the sequence is as yet only incompletely known. (Figs. 13 and 14, insert of photographs.) The upper, more accurately determined part is the following.

	Feet
Wandagee Hill series[23]	
Coarse-grained sandstones, partly cross-bedded. Few fossils	700
Wandagee series. Well bedded fine- to medium-grained sandstones and shales. Very fossiliferous	2,350
(d) "*Linoproductus* stage." Fine- to medium-grained sandstones, in many places strongly ferruginous	1,000
(c) "*Schizodus* stage." Well bedded, shaly and friable sandstones, greenish gray to brown. Rich in fossils (pelecypods) in some places, almost unfossiliferous in others	190
(b) "*Calceolispongia* stage." Gray, fine- to medium-grained sandstones and gray and black shales. Very fossiliferous	600
(a) "*Lingula* stage." Carbonaceous and gypseous shales, with some sandstone and limestone horizons (the latter fossiliferous)	560
Cundlego series. Fine-grained shaly to coarse-grained massive sandstone, commonly cross-bedded, with many intercalations of shale. Fossils in some layers only	1,000
Bulgadoo series. Gray to black carbonaceous shales, in places gypseous, with very few sandstone beds. Not very fossiliferous	2,200

[21] H. W. B. Talbot, "Geological Observations in the Country between Wiluna, Hall's Creek, and Tanami," *Geol. Survey Western Australia, Bull. 39* (1910). See also the brief of account of L. J. Jones' traverse in R. A. Hobson, "Summary of Petroleum Exploration in Western Australia to January 1935," *Geol. Survey Western Australia, Ann. Progr. Rept. 1935* (1936), pp. 24, 25.

[22] Mostly known from unpublished observations b ythe writer in 1938, 1939, 1940 and 1941.

[23] Provisional name, introduced in C. Teichert, *Permian Crinoid Calceolispongia* (in press). At present the correlation of these sandstones toward the north and south is unknown.

The total thickness of these rocks is 6,250 feet, but it is not known how far they are above the base of the Permian sequence; it seems, however, likely that another 3,000 to 3,500 feet of sediments are present. The total thickness of the Permian in this section is, therefore, probably about 10,000 feet.

From present information it seems that the thickness decreases southward. Raggatt found the following section in the vicinity of the Gascoyne River, 75 miles farther south (about 25° S. Lat.).

	Feet
Kennedy series. Sandstones	700
Byro series. Mudstones, shales, sandstones, sandy limestones	2,400
Wooramel series. Medium-grained white sandstones. Up to	180
Callytharra series. Limestones and mudstones. Up to	460
Lyons series. Limestones, sandstones, glacial conglomerates. Up to	2,400
Total up to	6,140

The Callytharra series is represented in the Minilya River section by 675 feet of calcareous shales and limestones—a thickening of more than 200 feet as compared with the Gascoyne section. (Fig. 12, insert of photographs.) The Wooramel sandstone series has not been accurately measured in the Minilya section, but is certainly not less than 180 feet. No figures are at present available for the Lyons series in the Minilya area.

The country south of the Gascoyne River has only been superficially examined but from data collected by Dee and Rudd it seems that along the Wooramel River, 50 miles south of the Gascoyne, the thickness of the Permian might have decreased to something like 2,800 feet although this might represent a very conservative estimate.

Apart from the great thickness of the beds in the northern part of the basin, the most noteworthy feature is that the sequence is entirely marine. Here is found the only wholly marine Permian sequence in Australia and without doubt *one of the thickest marine Permian sequences in the world.*

(3) *South-West Division.*—In the southwestern part of the state there are a number of scattered areas of Permian rocks. Good outcrops of marine strata are found 30–40 miles from the coast of the Indian Ocean on the Irwin River near, and east of, Mingenew (29° 10′ S. Lat.), as well as farther north and south. (Fig. 15, insert of photographs.)

Excellent sections are seen in the two branches of the Irwin River, known as North Irwin and South Irwin, where the sequence is as follows.

	Feet
White sandstone and shales	200
Carbonaceous shales with ferruginous sandstones layers and erratic boulders	120
Coal Measures. Laminated and cross-bedded, plant-bearing sandstones with several coal seams	140
Fossil Cliff limestone; richly fossiliferous shale with limestone layers	190
Metalegoceras series. Mostly non-fossiliferous shales with limestones and claystones	2,500
Tillites, calcareous grits, and Fontainebleau sandstones	200
Total	3,350

As far as known at present the area covered by these sediments is not more

than about 100 square miles. They are folded into a flat north-pitching anticline. However, fossiliferous sandstones occur in the immediate vicinity of Mingenew and it is quite possible that marine Permian rocks have a much wider distribution in that part of the country. No other areas of marine Permian are known in the South-West Division, but some non-marine sedimentary basins may be briefly mentioned. One of these is the Eradu basin, where conglomerate sandstones and shales with interbedded coal seams have been found to a depth of about 1,200 feet.[24] The thickest coal seam is 22 feet thick, but unfortunately like the Irwin River coal the Eradu coal is of low heating quality (more in the nature of a brown coal). Nevertheless both coal fields are at present being tested for their economic possibilities.

From Eradu the sediments continue eastward below the surface, for 13½ miles farther east, in the direction of Mullewa, 1,360 feet of sandstone and shale were traversed by a bore, but no coal seams were found here. It is possible that these beds extend more or less continuously farther east and southeast and that they are continuous with the outcrops of the Irwin River district.

The southern continuation of this belt of Permian strata is likewise a matter for speculation. A deep bore at Moora, more than 100 miles south of Mingenew, penetrated almost 1,100 feet of grits, sandstones, shales, and a few limestones, below the lowest bed with Jurassic plants (probably Lower Jurassic), and the suggestion that these beds represent the continuation of the Irwin River Permian seems altogether reasonable.

Nothing further is known of the Permian until the Collie coal field is reached,[25] at present the only productive coal field of Western Australia. It is situated 100 miles south of Perth (about 33° 10′ S. Lat.). Although the full extent of the basin is unknown, it is not less than 100 square miles. The succession consists of sandstone and shale with interbedded coal seams of an aggregate thickness of 130 feet. The total thickness of the sediment is unknown, but is probably not less than 2,000 feet. (Fig. 16, insert of photographs.)

A Permian age is proved by the abundant occurrence of *Glossopteris* and *Gangamopteris* in certain beds. The area is well outside the Coastal Plain, situated on the pre-Cambrian shield, and the sediments are downfaulted.

South-southeast of the Collie basin is the Wilga basin with at least 700 feet of sandstones and shales with coal seams which have not yet been commercially exploited. Additional minor basins might exist farther south, of which the Fly Brook basin may be an example.

Coal has also been struck in bores near Bunbury on the west coast and in the sedimentary area south of Bunbury between the Western Australian Plateau and the Cape Leeuwin-Naturaliste horst in the west, but it can not be decided whether these little known sediments are of the same age or younger.

[24] T. Blatchford, "Boring for Coal in Eradu District by State Aid," *Geol. Survey Western Australia, Ann. Progr. Rept. 1929* (1930), pp. 15–19.

[25] J. M. Limb and C. R. Kent, "Western Australian Coal Resources and Their Utilization," *Railway and Tramway Mag.* Perth (1939). Also issued as separate pamphlet by Railway and Tramway Inst. Counc. Perth (1939). 32 pp.

(4) East Kimberley Division (Burt Range basin).[26] Very little can be said about the section in this part of the country at the present moment. In the Burt Range, close to the Northern Territory boundary, a conglomerate of about 50 feet was seen to rest with a very slight unconformity on the Carboniferous Bryozoan limestone. The conglomerate is followed by about 70 feet of coarse-grained sandstone and by several hundred feet of still higher beds which could not be examined.

However, elsewhere in that vicinity thick conglomerates were found which were quite unlike any Cambrian, Devonian, or Carboniferous rocks known in that district. These conglomerates seem to form a considerable part of the southernmost part of the Burt Range and are separated from the Devono-Carboniferous section of the central Burt Range by a major fault. The conglomerate is here fully 500 feet thick. There is very little indication of bedding and no sorting at all. Pebbles and boulders of any size up to 2 feet in diameter occur rather tightly packed together. The same rock forms a prominent hill a few miles south, about one mile north of Cockatoo Spring, where more than 500 feet must be exposed. Although no scratched or faceted pebbles were found, a glacial origin of the conglomerate is perhaps not impossible. Elsewhere in the East Kimberley similar conglomerates occur associated with red sandstones, as on the east side of Mt. Misery, and the same conglomerate may also be distributed farther inland, west of the Ord River, in the Conglomerate or Ragged Range. Blatchford's[27] description and pictures of the rocks of this range agree so closely with the conglomerates north of Cockatoo Spring and in southern Burt Range that there can be little doubt that they belong to the same series. It is also possible that a thick series of sandstones and white shales at Mt. Brooking and vicinity is of the same age, though this is at present hardly more than a suggestion.

PERMIAN CORRELATION

For a long time correlation of the Permian rocks of Western Australia has been difficult. At first they were regarded as Carboniferous. At a later stage they were, in common with contemporaneous sequences in eastern Australia referred to as "Permo-Carboniferous." In this case, the question of the boundary between the Carboniferous and the Permian was usually left open, but sometimes the lower tillites and the lowest fossiliferous beds were more specifically assigned to the Upper Carboniferous. When in later years the Permian affinities of all the faunas were recognized, it was at first believed that the entire Permian was represented in Western Australia and some beds were referred to the Lower Permian, others to the Middle, and still others (Wandagee and Byro series of the North-West) to the Upper Permian.[28]

[26] C. Teichert and R. S. Matheson, "Geological Reconnaissance in the Eastern Portion of the Kimberley Division, Western Australia," *Geol. Survey Western Australia, Ann. Progr. Rept. 1945.* Perth (1946).

[27] T. Blatchford, "Geological Observations Made whilst Travelling in West Kimberley, &c.," *Geol. Survey Western Australia, Ann. Progr. Rept. 1927* (1928), p. 14.

[28] See, for example, the very able analysis of North-West Permian faunas by H. G. Raggatt and

It was only when ammonoids and other fossils of great chronological value were discovered in the Western Australian Permian in greater numbers[29] that it was possible to put the correlation of the beds on a more exact basis. The conclusions thus reached were fully supported by a study of the corals.[30]

Even the thickest sections known in Western Australia represent only part, almost certainly not more than half, of Permian time. It is probable that sedimentation in all marine basins started more or less simultaneously very early in the Permian. The main glacial period during which most of the glacial sediments (tillites, *et cetera*) were deposited is the Lower Permian, or Sakmarian, age. During this period as much as 3,000 feet of sediments, mostly coarse clastics, were deposited over wide areas in the Irwin River district, in the North-West and in the Kimberley Divisions. The bulk of all the sediments, however, is of Artinskian age (sometimes called Middle Permian) and there are probably only comparatively small thicknesses of post-Artinskian sediments present anywhere in Western Australia. There is certainly no marine Upper Permian in the generally accepted sense anywhere in this state.

There is in general good correlation between the North-West and Desert basin sequences. In both these areas sedimentation went on throughout Artinskian time and continued for a short time after the Artinskian. The ammonites now known in the higher marine beds of the North-West (mostly Wandagee series) include *Propinacoceras australe*, *Paragastrioceras wandageense*, *Pseudogastrioceras goochi*, and *Agathiceras applanatum*.

In addition the bradyodont shark *Helicoprion*, an important zone fossil of the Artinskian, is present in the *Linoproductus* beds. In a lower stratigraphical position occur species of *Metalegoceras*, *Pseudoschistoceras*, and *Thalassoceras*, partly of Artinskian and partly of Sakmarian affinities. The corals of all these beds also indicate an Artinskian to only very slightly younger age.

The exact correlation of the Western Australian Permian is of great paleogeographical significance. The Artinskian alone is in places represented by as much as 6,000 or even 7,000 feet of sediments. To enable this sequence to be accumulated in such a short time the rate of denudation of the sediment-yielding land must have been tremendous and geological processes that led to considerable uplift and the formation of a pronounced relief must have preceded and accompanied the sedimentation processes.

It is at present impossible to say to what stage of the Permian those coal

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H. O. Fletcher, "A Contribution to the Permian-Upper Carboniferous Problem and an Analysis of the Fauna of the Upper Palaeozoic (Permian) of North-West Basin, Western Australia," *Rec. Aust. Mus.*, Vol. 20 (1937), p. 181.

[29] C. Teichert, "*Helicoprion* in the Permian of Western Australia," *Jour. Paleon.*, Vol. 14 (1940), pp. 140–149.

———, "Permian Ammonoids from Western Australia," *ibid.*, Vol. 16 (1942), pp. 221–32.

———, "Two New Ammonoids from the Permian of Western Australia," *ibid.*, Vol. 18 (1944), pp. 83–89.

[30] D. Hill, "A Re-Interpretation of the Australian Palaeozoic Record, Based on a Study of the Rugose Corals," *Proc. Roy. Soc. Queensland*, Vol. 54 (1943), pp. 53–66.

measures belong that are not associated with marine beds: Eradu, Collie, Wilga *et cetera*, except that they were probably not formed very early in the Permian when the climate of Australia was rigorous.

TRIASSIC

The occurrence of strata of Triassic age in Western Australia is very doubtful. In the extreme southwest part of the state sandstones occur in various places in disconnected outcrops, or below the surface. In the vicinity of Donnybrook, about 30 miles east-southeast of Bunbury (about 33° 35′ S. Lat.), sandstones rest on pre-Cambrian gneisses. At least some of these were deposited in very shallow water as evidenced by the occurrence of asymmetrical ripple-marks and of the footprints of a small four-footed vertebrate which were found in a small quarry near Brookhampton. A considerable thickness (more than 1,000 feet) of sandstones and shales interbedded with a few coal seams has been penetrated by bores in the coastal plain east of Bunbury; these may possibly be of the same age as the Donnybrook sandstones.

Another area of sedimentary rocks in the southwest corner of the state is situated in a belt of low country extending from Busselton southward to Flinders Bay and between the southwestern corner of the Great pre-Cambrian Plateau of Western Australia in the east and a ridge of pre-Cambrian between Cape Naturaliste and Cape Leeuwin in the west. Hardly anything is known about this sedimentary area.

Some of these sediments may be equivalents of the Collie-Wilga series of Permian age and it has therefore long been customary to refer the Donnybrook sandstone to the Permian (or "Carboniferous" of earlier reports). On the other hand, the existence at the time of the deposition of at least some of the sandstones of a small four-footed animal that made a narrow track and consequently must have had its body well elevated above the ground does not support a Paleozoic age of these rocks. Maitland has advocated a Triassic age for them, pointing out lithological resemblances to Triassic rocks in regions as far away as New South Wales, Tasmania, and South Africa.[31]

It seems that positive evidence for such correlations is lacking. Also, it is quite possible that not all sandstones at present mapped as "Donnybrook sandstone" are actually contemporaneous. Some are no doubt younger than Paleozoic, others might well be of the age of the Collie coal measures. Some of the sandstones contain some secondary gold deposits which have been mined.

JURASSIC[32]

DISTRIBUTION

Jurassic rocks, both of the marine and of the lacustrine facies, occur rarely more than 100 miles or so inland. From south to north the main areas of distribu-

[31] A. Gibb Maitland, "The Donnybrook Sandstone Formation and Its Associates," *Jour. Roy. Soc. West. Australia*, Vol. 25 (1938–1939), pp. 177–95. 1940.

[32] The latest official geological map of Western Australia, published by the Geological Survey of

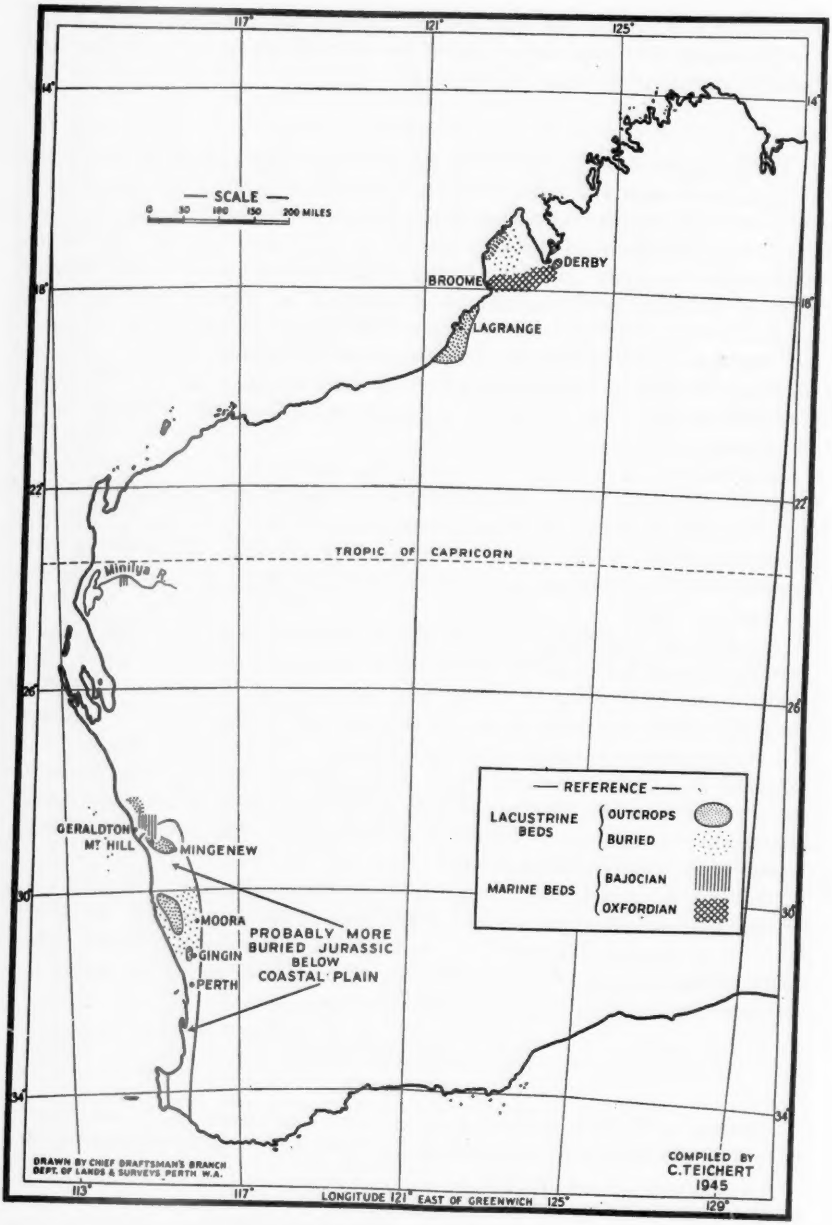

FIG. 17.—Distribution of Jurassic rocks.

tion of Jurassic rocks are the following. (1) Disconnected occurrences in the coastal belt north of Perth as far as Mingenew (about 32° to 29° 15′ S. Lat.). Lacustrine beds only occur in this belt. (2) The vicinity of Geraldton (about 29° to 28° 40′). Marine and lacustrine beds. (3) A small outcrop on the Minilya River, about 45 miles from its mouth (114° 25′ E. Long.). Marine. (4) In deep bores at Broome (18° S. Lat.). Marine. (5) Disconnected outcrop areas north and south of Broome and in the vicinity of Derby. Lacustrine beds only.

SUCCESSION

Since rocks of the lacustrine facies are at least in part older than the marine beds, they may be considered first.

Lacustrine facies.—The Coastal Plain north of Perth is a gradually widening belt of generally flat, low country between the coast and the edge of the Western Australian tableland of pre-Cambrian rocks. Most of the Coastal Plain is sandy country with scattered outcrops and small outcrop areas here and there. A common rock type is brown ferruginous sandstone, and, because some of these sandstone contain Jurassic plants, there has been a certain tendency—perhaps not always justified—to include most ferruginous sandstones in this part of the state in the Jurassic. Perhaps the most interesting record is from the deep bore at Moora, 100 miles north of Perth, which penetrated 2,230 feet of sediments, mostly sandstones and grits. Between 1,011 and 1,147 feet (405 to 541 feet below sea-level), shales with *Taeniopteris* and *Otozamites* were traversed—two plant genera characteristic of Jurassic lacustrine beds elsewhere in Western Australia.

At Gingin, 60 miles north of Perth, the fossiliferous Cretaceous series rests on brownish, fine-grained, clayey sandstones of unknown thickness which contain *Isoetites*, *Cladophlebis australis*, *Thinnfeldia talbragarensis*, *Taeniopteris spatula*, *Ptilophyllum pecten*, and other plants of Jurassic age.[33] About 40 miles farther north at Dandarragan, Cretaceous strata rest on a series of coarse-grained red and gray sandstones which is several hundred feet thick and which may also be Jurassic in age, although no fossils have been found so far. Sandstones with *Otozamites* are also found near Mingenew in an outcrop area which may be more or less continuous with ferruginous *Otozamites* sandstones which underlie the marine Middle Jurassic beds south of Geraldton, at Mt. Hill.[34] Here these sandstones rise to at least 1,000 feet above sea-level, possibly higher. Not far north, however, the lacustrine beds disappear, for only 15 miles farther north (and about 20 miles east of Geraldton) marine Middle Jurassic rests on pre-Cambrian gneisses.

Western Australia in 1933, shows a more or less continuous belt of Jurassic along, or close to, the west coast of the state from 30 miles north of Perth as far as the Fortescue River (31° 35′ to 21° 05′ S. Lat.), and from the vicinity of Walal to King Sound (19° 55′ to 16° 20′ S. Lat.). A considerable part of this belt of rocks is now known to be Cretaceous in age.

[33] A. B. Walkom, "Fossil Plants from Gingin, W. A.," *Jour. Roy. Soc. Western Australia*, Vol. 28 (1941–1942), pp. 201–07. 1942.

[34] W. D. Campbell, "The Irwin River Coalfield, and the Adjacent Districts from Arrino to Northampton," *Geol. Survey Western Australia, Bull. 38* (1910), pp. 60–62.

The Dongarra and Yardarino bores near the coast west of Mingenew have penetrated soft sandstones and shales to depths of 2,112 feet and 1,607 feet, respectively; no fossils are available from these bores and although some authorities have suggested a Jurassic age for these beds, they may well be Cretaceous, or even Tertiary.

In summary it may be stated that lacustrine Jurassic sandstones underlie probably the whole of the Coastal Plain in the Southwest Division north of Perth and that their thickness certainly exceeds 1,000 feet and may even be in excess of 2,000 feet. Since these beds underlie marine strata of middle Bajocian age at Mt. Hill, it can be concluded that the bulk of them must be Lower to very early Middle Jurassic in age.

Similar sandstones occur in the coastal strip from somewhere south of Broome to north of Derby, in the Kimberley Division. Fine- to medium-grained micaceous sandstones, in places cross-bedded, crop out at Pt. Gantheaume and Entrance Point near Broome as well as farther south at Cape Villaret and farther inland, 50 miles south of Langrange, where tabletop hills rise 100 to 130 feet above the general level of the Desert basin.[35] Such sandstones are also known to occur intermittently along the coast north of Broome as far as Beagle and Pender bays.

At Point Torment on the east side of King Sound, north of Derby, friable sandstones and clays with *Thinnfeldia feistmanteli*, *Dicroidium*, *Otozamites*, and *Ptilophyllum* occur, and a southward continuation of these beds was found near Derby, where they were traversed by a bore from the surface down to at least 300 feet below the surface.[36] From the general structure of the area it seems likely that these plant beds (Derby series) are higher than the marine Oxfordian found 20 miles farther south in a bore at Yeeda (see below) and that they are therefore of late Jurassic age, i.e., younger than the *Otozamites* sandstones of the South-West.

Marine facies.—The principal outcrop area of marine Jurassic rocks in Western Australia is in the country east and southeast of Geraldton, although the area has never been accurately mapped and the section has never been studied in detail. Its thickness may be expected to be a few hundred feet. East of Geraldton these marine rocks rest on pre-Cambrian gneisses. A good exposure of the unconformity is seen in a railway cutting nineteen and a half miles east of Geraldton on the line to Mullewa. The pre-Cambrian is here overlain by a few feet of conglomerate, followed by fossiliferous clays and calcareous sandstones. The rich fauna of these beds includes many pelecypods, among them species of *Cucullaea*, *Trigonia*, *Pecten*, *Ctenostreon*, *Alectryonia*, and others, but also many belemnites of the *Belemnopsis* group, ostracodes, and especially ammonites. The latter are of course of particular importance for the correlation of the beds. Spath[37] thinks

[35] F. G. Clapp, "A Few Observations on the Geology and Geography of North-West and Desert Basins, Western Australia," *Proc. Linn. Soc. New South Wales*, Vol. 25 (1926), pp. 59–60.

[36] E. Antevs, "Some Mesozoic Plants" (Res. Mjobergs Swed. Scient. Exp. to Australia 1910–13. V). *Kungl. Svenska Vet. Ak. Handl.*, Vol. 52, No. 5 (1913). 6 pp.

[37] L. F. Spath, "On Jurassic Ammonites from Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 25 (1938–1939). pp. 123–35, 1939.

that more than one ammonite zone might be represented, but in a general way he correlates the beds with the *sauzei* and *sowerbyi* zones (Middle Bajocian) of the English succession.

From the area east of Geraldton outcrops of the marine Jurassic must extend southward at least as far as Mt. Hill and vicinity, though it is not known if they are continuous. As has already been mentioned, the marine starta are at Mt. Hill underlain by plant-bearing lacustrine beds.

All these marine beds may be called *Newmarracarra* series, a name which is here proposed, but in using which it should be remembered that its scope is as yet very incompletely defined.

The Jurassic beds near Geraldton have probably been deposited on a very irregular surface. Two miles north of Geraldton, at Bluff Point, the pre-Cambrian is at the surface. In the Geraldton Town Bore granite was reached at 420 feet, the overlying sediments being mostly sandstone with one coal seam at 129 feet. Only a few miles east of the town however, 1,531 feet of sandstones and shales were penetrated in the Racecourse Bore without reaching bedrock, though part of the sediments may be Permian. Some of these differences in thickness of the sediments may be due to tectonic movements and erosion after the Jurassic.

No marine Jurassic is known anywhere north of Geraldton until approximately 23° 45′ S. Lat. is reached. Here a small outcrop area of quartzose and calcareous sandstones, less than 25 feet thick, was found[38] on the south bank of the Minilya River which contains some pelecypods and an algal bed with *Parachaetetes megalocytus* Pia. These beds occur in a small fault block between Cretaceous and Permian strata and are believed to be of the same age as the Newmarracarra series. Their distribution elsewhere in the North-West Division is at present unknown.

Finally, marine Jurassic of somewhat younger age occurs farther north, at Broome, where sandstones and shales with *Buchia subpallasi*, *Buchia subspitiensis*, and species of *Belemnopsis* have been pierced in bores between about 1,150 and 1,390 feet below sea-level. This is a typical East Indian assemblage of Oxfordian age.[39] The total thickness of Jurassic in these bores is probably about 550 feet.

It is believed that these Oxfordian beds may underlie considerable portions of the coastal areas in this part of Western Australia, for an extension was found much farther inland, about 20 miles south of Derby and almost 100 miles east-northeast of Broome.[40]

CRETACEOUS

DISTRIBUTION

Cretaceous rocks in Western Australia are almost exclusively marine. They have a wide, perhaps almost continuous distribution along the west coast, al-

[38] C. Teichert, "Marine Jurassic in the North-West Basin, Western Australia," *Jour. Roy Soc. Western Australia*, Vol. 26 (1939–1940), pp. 17–25. 1940.

[39] C. Teichert, "Marine Jurassic of East Indian Affinities at Broome, North-Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 26 (1939–1940), pp. 103–19. 1940.

[40] C. Teichert, "Marine Upper Jurassic near Derby, North-Western Australia," *Aust. Jour. Sci.*, Vol. 5 (1942), pp. 33–34.

though they are not everywhere exposed on the surface. From the south the following areas of marine Cretaceous are known.

1. The Gingin-Dandarragan area, 60 to 110 miles north of Perth, is composed of marine rocks.

2. An area along the lower course of the Murchison River is composed of estuarine and marine sediments. This is probably continuous, though not all the way in surface exposures, with the next-following area.

3. A long belt of Cretaceous rocks begins to crop out somewhere north of Carnarvon and extends to the southern end of Exmouth Gulf.[41] The southern continuation of this belt has been traced in bores as far as Carnarvon, but it probably continues farther south and may be continuous with the Cretaceous belt south of Shark Bay.

Furthermore, Cretaceous rocks occur below the Tertiary limestones of the Nullarbor Plain in the Eucla Division, though they are not exposed anywhere in this area.

In addition, there are larger and smaller outcrop areas farther inland, with rocks of somewhat doubtful correlation which are now mostly regarded as Cretaceous.

SUCCESSION

The sequences in the three main outcrop areas of marine rocks are so different that each must be described separately.

1. *Gingin-Dandarragan area.*—It is peculiar that, although this area is comparatively close to Perth and its geology is well known to local geologists, no detailed description has been published. Gingin may be regarded as the type locality of this area.[42] The section here is as follows.

	Feet
Upper Greensand	140
Chalk	70
Lower Greensand	20
	230

The Lower Greensand rests on plant beds of Jurassic age. It is very rich in glauconite and has furnished very few fossils. Its transition into the overlying chalk is somewhat gradual, the chalk itself being in places extremely fossiliferous.

However, its fossil content varies greatly even over very short distances and in places it contains very few fossils. Ammonites are rare, though a number of specimens belonging to species of the *Pachydiscus* group have been found.[43] Among the more characteristic fossils are the crinoids *Marsupites* and *Uinta-*

[41] The area covered by this Cretaceous belt is shown partly as Tertiary, partly as Jurassic, and partly as Permian on the latest official geological map of Western Australia (1933).

[42] F. R. Feldtmann, "The Glauconite Deposits at Gingin, South-West Division." *Geol. Survey Western Australia, Ann. Progr. Rept. 1933* (1934), pp. 6–8.
E. de C. Clarke, R. T. Prider, and C. Teichert, *Elements of Geology*, p. 274. Perth (1944).

[43] L. F. Spath, "Note on Two Ammonites from the Gingin Chalk," *Jour. Roy. Soc. Western Australia*, Vol. 12 (1926), pp. 53–55.

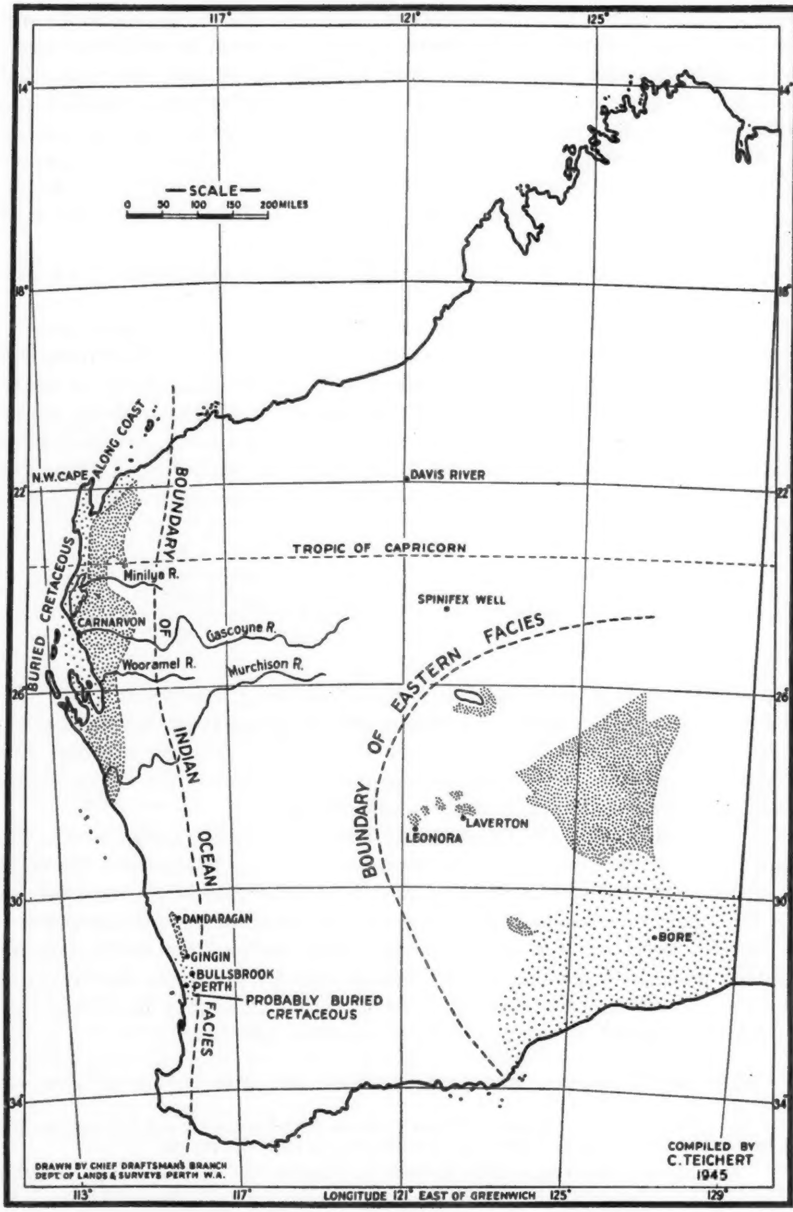

FIG. 18.—Distribution of Cretaceous rocks. *Dense stippling:* outcrop areas; *wide stippling:* buried Cretaceous.

crinus, a few small brachiopods, some crustaceans, and many pelecypods. Among the latter large specimens of *Inoceramus* are very common. In 1938 a specimen almost 20 inches long was excavated from a chalk deposit near Ginginup. The chalk has an interesting assemblage of detrital minerals[44] which include, in addition to the light fraction (glauconite, quartz, feldspar), opaque minerals, zircon, garnet, rutile, tourmaline, epidote, staurolite, amphibole, kyanite, anatase, as well as others present in minor quantities. Its $CaCO_3$ content varies between 75 and 89 per cent and it is thus much less pure than the British chalk which may contain up to 98 to 99 per cent calcium carbonate.

The boundary with the Upper Greensand is sharp in most places. No fossils have been found in the latter.

North of Gingin the chalk wedges out and the greensands disappear under a cover of sand and laterite so that the exact northern boundary of the Cretaceous area can not be stated. Under the surface it may be continuous with the larger Cretaceous area of Dandarragan which begins north of the Moore River, about 12 miles farther north (31° S. Lat.). This is an area of about 350 square miles where the sequence is essentially the same as that at Gingin[45] except that the Lower Greensand contains two phosphate beds, of which there is little if any trace at Gingin.

	Feet
Upper Greensand	60
Chalk	20–40
Upper Phosphate bed	2
Lower Greensand	20–70
Lower Phosphate bed	2

This series rests on a sequence of several hundred feet of sandstones which may be Jurassic in age. The Phosphate beds consist of phosphate nodules and phosphatized wood and the Upper bed contains remains of ichthyosaurian and plesiosaurian reptiles. The chalk contains the same fossils as the Gingin chalk. The Upper Greensand appears to be non-fossiliferous.

The chalk of Gingin and Dandarragan belongs to the *Marsupites* zone of the Senonian. It is Santonian, that is, Middle Senonian, in age.[46] Because of the small thickness of the Lower Greensand it may be considered most probably still in the Santonian, whereas the Upper Greensand is almost certainly Campanian.

Nothing definite can at present be said about the southern continuation of the Gingin beds. It is possible that Cretaceous beds are present in the vicinity of Perth at more than 1,650 feet below sea-level, but these may be Lower Cretaceous[47] not known in outcrops in the South-West Division.

[44] D. Carroll, "A Note on the Mineralogy of the Gingin Chalk, Western Australia," *Proc. Geol. Assoc.*, Vol. 50, Pt. 2 (1939), pp. 227–34.

[45] C. Teichert and R. S. Matheson, "Upper Cretaceous Ichthyosaurian and Plesiosaurian Remains from Western Australia," *Australian Jour. Sci.*, Vol. 6 (1944), pp. 167–70.

[46] The Santonian is often regarded as the lower section of the Senonian, depending on whether or not the Coniacian is included in the Senonian. The writer here follows the usage adopted by S. W. Muller and H. G. Schenck (*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), p. 272).

[47] Based on identification of microfossils by I. Crespin; see W. J. Parr, "Upper Eocene Foraminif-

2. *Murchison River area.*[48]—There are good outcrops all along the lower course of the Murchison River from its mouth upstream as far as about 25 miles from the coast, where the Cretaceous sediments are faulted against the pre-Cambrian. The following sequence of rocks is exposed in this area.

Name	*Lithology*	*Fossils*	*Thickness in Feet*
Second Gully shale	Light green, hard, glauconitic shales	—	92+
Toolonga chalk	Mostly pure chalk, in places glauconitic. In many places with a 6-inch layer of phosphate nodules at base and commonly rich in chert nodules in upper part	Foraminifera, *Cidaris*, *Marsupites*, *Uintacrinus*, *Gryphaea*, *Inoceramus*, brachiopods	35–120
Alinga beds	Glauconitic shales, commonly sandy and with greensand pockets, grading into greensand	Belemnites	10–75
Thirindine shale	Whitish to gray, siliceous shale, in places more massive and grading into siltstone	Very poor belemnite fragments rare	0–63
Butte sandstone	Predominantly non-bedded pure quartz sandstone, mostly loosely cemented or incoherent ("running sand"); uppermost part ordinarily ferruginous and glauconitic	Vertical and oblique burrows, fossil wood, rare	75–170
Tumblagooda sandstone	Predominantly reddish and purple sandstones, as a rule strongly cross-bedded, but grading into well bedded sandstones above	Vertical burrows and invertebrate trails on bedding planes	400+

The Tumblagooda sandstone is essentially a deltaic deposit that is derived from a general source area situated somewhere in the east, or more correctly probably east-southeast.

The series of sediments above the Tumblagooda sandstone was deposited in a gradually subsiding and deepening basin. The only richly fossiliferous deposit is the Toolonga chalk which contains fossils identical with those of the Gingin chalk farther south and is therefore of the same age—Middle Senonian. The chalk forms cliffs on the north side of the Murchison River as far as 12 miles inland and extends northward along the coast an unknown distance, though not less than 20 or 30 miles. (Fig. 19, insert of photographs.)

North of the Murchison River there are no outcrops almost as far as Shark Bay, 75 miles north, except probably along the coast which has not yet been

era from Deep Borings in Kings Park, Perth, Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 24 (1937–1938), p. 71.

[48] E. de C. Clarke and C. Teichert, "Cretaceous Stratigraphy of Lower Murchison River Area, Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 31 (1944–1945) (in press).

examined geologically. There is, however, little doubt that the Cretaceous continues beneath a comparatively thin coat of drift sand and superficial travertine deposits.

The Cretaceous is at the surface east of Hamelin Pool (about 26° 25′ S. Lat.) where non-fossiliferous white and yellow shales with chert bands occur. This area is only 100 miles from Carnarvon where Cretaceous strata occur below the surface.

The total thickness of the Cretaceous in the Murchison River area is approximately 750 feet, probably slightly greater, though hardly in excess of 1,000 feet.

3. *Area between Carnarvon and Exmouth Gulf.*[49]—The best outcrops are in the northern part of this area in the Cardabia Range and the country east of it. The Cretaceous beds are here thrown into a broad anticline in which Lower Cretaceous is exposed along the center and Upper Cretaceous along both flanks. (Fig. 20, insert of photographs.)

A composite section in this area is as follows.

		Thickness in Feet
Cardabia series 1,070 feet	Sandy, white to yellow bryozoan limestone	85
	Glauconitic sand with ammonites	5
	Inoceramus marls	115
	Chalk, with chalky clays and calcareous claystones	865
Winning series 1,100 feet	Cherts, shales, and siltstones	110
	Mudstones, glauconite sands and shales	990

The Lower Cretaceous is not very fossiliferous, although the belemnite *Dimitobelus diptychus* is locally very abundant in greensands and shales. A small fauna of pelecypods including *Maccoyella*, *Syncyclonema*, *Trigonia*, and other genera, is also known. The Winning series is at present considered to be Albian in age but further evidence, especially micropaleontological, should be awaited.

In the Upper Cretaceous Cardabia series it is interesting to note that the chalk occurs fairly low in the sequence and that Irene Crespin, on foraminiferal evidence, thinks that its age is Turonian which is decidely older than the chalk deposits of the southwest part of Western Australia. The same author gives the age of the overlying glauconite sands, on evidence of the Foraminifera, as Santonian, whereas Spath, who has studied the ammonoids from the same beds,[50] regards them as Lower Maestrichtian although he leaves open the possibility of their being of late Campanian age. But even the latter alternative would leave a wide gap in the determination of the age of this bed by these two authorities.

[49] H. G. Raggatt, "Geology of North-West Basin, Western Australia, with Particular Reference to the Stratigraphy of the Permo-Carboniferous," *Jour. Proc. Roy. Soc. New South Wales*, Vol. 70 (1936) pp. 153–62.
I. Crespin, "Upper Cretaceous Foraminifera from the Northwest Basin, Western Australia." *Jour. Paleon.*, Vol. 12 (1938) pp. 391–95.

[50] L. F. Spath, "On Upper Cretaceous (Maestrichtian) Ammonoidea from Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 26 (1939–1940), pp. 41–57.

However, Spath's ammonites were collected by the present writer, whereas Miss Crespin's Foraminifera came from Raggatt's collection and there is thus of course the possibility that the collections might not have been derived from strictly the same horizon. Spath suspected that even the writer's ammonite collections might represent two closely related biozones and not one as the writer had thought in the field.

The ammonites in this bed are an interesting assemblage which closely resembles the fauna of the Valudayur and Aryalur groups of southeastern India and includes species of *Paraphylloceras*, *Phyllopachyceras*, *Pseudophyllites*, *Hauericeras*, *Kossmaticeras*, *Diplomoceras*, *Glyptoxoceras*, and *Eubaculites*.

The top Bryozoan limestone may be either Upper Maestrichtian or Danian in age. The *Inoceramus* marles below the ammonite greensand may correspond with the Gingin and Toolonga chalk of the Southwest Division, although the faunas are somewhat different.

The total thickness of the Cretaceous, combined from various sources is given by Raggatt as more than 2,000 feet. From bore logs and surface data given by Forman,[51] it appears that there is a general increase in thickness in a westerly direction from about 1,600 feet east of Cardabia Range to approximately 2,200 feet west of Cardabia Range, where the Cretaceous is buried under Tertiary rocks. Raggatt suggests a thickening of the Cardabia series of about 200 feet in a southerly direction between Cardabia Range and Carnarvon.

Cretaceous outcrops extend from Cardabia Range southward as far as the Lyndon River. South of the Lyndon outcrops of the Cretaceous are scattered and far between, though the writer has found Upper Cretaceous fossils in a limestone ridge about 15 miles south of the Minilya River and east of the big Salt Lake. This occurrence is due west of the outcrops of the siltstones of the Winning series at Barrabiddy Hills (Trigonometrical Station K56) and it is possible that a more or less continuous west-dipping sequence of Cretaceous is present in this area.

4. *Buried Cretaceous of Eucla Division.*—The Tertiary limestone which covers large areas in this Division has been penetrated by a few deep bores which have reached the underlying strata.[52] Cretaceous fossils have only been found in one of the bores, near the intersection of the railway line and the 127th meridian E. Long., where the section is as follows.

	Feet
Eucla limestone (Miocene)	603
Shales	667
Fine and coarse sand with hard bands and granite boulders	74
Granite	28

Below the Eucla limestone, presumably in the shales, specimens of *Aucella hughendensis* and *Maccoyella corbiensis* were obtained. These are two character-

[51] F. G. Forman, "Artesian and Sub-Artesian Water Possibilities on Cardabia Station, North-West Division," *Geol. Survey Western Australia, Ann. Progr. Rept. 1938* (1939), p. 7.

[52] Boring for Water on the Transcontinental Railway Line," *Geol. Survey Western Australia, Ann. Progr. Rept. 1914* (1915), pp. 13–14.

istic fossils of the eastern Australian Lower Cretaceous and indicate an extension of the beds of that age into Western Australia. Other bores in the Nullarbor Plain reached the shales below the Eucla limestone at depths varying from 400 to 900 feet below the surface. The pre-Cambrian basement ("granite") was reached in two bores along the railway line and the thickness of the presumably Lower Cretaceous shales and sandstones was found to be 741 feet and 815 feet, respectively. Farther south toward the coast the Cretaceous obviously becomes thicker, for at Madura, on the edge of the Hampton Escarpment, 1,135 feet of sandstones, greensands, and shales, presumably Cretaceous in age, were penetrated below 905 feet of Eucla limestone but no bedrock was reached.

It has sometimes been stated that these beds may come to the surface somewhere north of the Nullarbor Plain where they might be continuous with the Wilkinson Range series of sandstones and boulder beds to be discussed next. However, the geology of this belt is unknown and any such correlation is at present entirely conjectural.

5. *Possible Cretaceous of interior.*—Special mention must be made of a sedimentary area of possibly considerable extent in the interior of Western Australia, about which, unfortunately, very little is as yet known.[53] Between Virginia Range and Warburton Range, for a distance of more than 200 miles, the country is entirely composed of horizontally bedded, slightly compacted, non-metamorphosed sandstones and claystones, with scattered boulder beds or residuals of such. Current-bedding is common in the sandstones and scratched and faceted pebbles have been collected from the boulder beds so that a glacial origin of these beds is suggested. This series has been termed Wilkinson Range series. Its beds probably extend westward to the neighborhood of Laverton and Leonora and southwestward as far as the Ponton River, although outcrops are not continuous and in some places only residuals of the boulder beds are left. Another possible extension is found farther north, that is, south, east, and northeast of Lake Carnegie where boulder clays with scratched and faceted pebbles have been found in numerous localities. Mostly they form flat-topped hills of whitish clay and clayey rocks which rest unconformably on the pre-Cambrian Nullagine series.

Southward there seems to be an extension of the same series in the direction of the Nullarbor Plain. The official Geological Map of Western Australia of 1933 shows an area of about 30,000 square miles occupied by the Wilkinson Range series but if all the sediments mentioned here are of the same age, the original area covered by them must have been at least 60,000 square miles.

However, it must be remembered that knowledge of these sediments is as yet of the scantiest nature and that nothing is known about the northern and eastern continuation of the sedimentary area.

In the absence of fossils a Cretaceous age has been advocated for the Wilkin-

[53] H. W. B. Talbot and E. de C. Clarke, "The Geological Results of an Expedition to the South Australian Border, &c." *Jour. Proc. Roy. Soc. Western Australia*, Vol. 3 (1918), pp. 11–16.

E. de C. Clarke, "Note on Occurrences of Boulders, Possibly Glaciated, near Leonora and Laverton, about Lat. 28°30′ South," *ibid.*, Vol. 6 (1919), pp. 27–31. (With note by A. Gibb Maitland.)

son Range series because of its lithological similarities with presumably Cretaceous sediments in South Australia. It must, however, be remembered that glacial sediments of Permian age are widely distributed in Western Australia and that a Permian age of the Wilkinson Range series can not at present be ruled out.

Other doubtful reports of sediments of possibly Cretaceous age come from widely separated points in the interior of the North-West Division.[54] Cherts with coccoliths occur on the Davis River near Survey Mark CC. 88 (approx. 22° S. Lat., 119° E. Long.) and glauconitic sandstone containing doubtful casts of Foraminifera and Radiolaria at Spinifex Well (24° 38′ S. Lat., 119° 38′ E. Long.). There is no definite proof of the Cretaceous age of either of these deposits which may well be remnants of the sediments of the Miocene transgression.

6. *Lacustrine beds.*—In view of the wide distribution of Cretaceous in lacustrine facies in central and eastern Australia, the meager record in Western Australia of such deposits of proved Cretaceous age is surprising. The only lacustrine, plant-bearing sandstones and shales at present regarded as Cretaceous in age are in the vicinity of Bullsbrook, 30 miles north of Perth, where they appear to be faulted down along the Darling fault scarp. They contain *Thinnfeldia, Taeniopteris, Nilssonia* and *Elatocladus.*[55]

TERTIARY[56]

DISTRIBUTION

Tertiary strata are widely distributed in Western Australia which provides a link between eastern Australian and East Indian faunal facies. Since Tertiary rocks have their main distribution in the coastal districts it may be convenient to consider the different areas in a clockwise direction.

1. Nullarbor Plain (Eucla Division). Tertiary limestones cover an area, large and semicircular, with a radius of about 175 miles, with its center near Eyre on the Great Australian Bight, and extending from Israelite Bay in the west as far as, and beyond, the South Australian boundary in the east.

2. About 100 miles west in the vicinity of the mining town of Norseman is an area of disconnected outcrops of limestones, dolomites, and sponge spicule beds.

3. Farther west is a belt of sandy and clayey rocks extending from the vicinity of Ravensthorpe to west of Albany, in places as much as 30 miles wide.

4. On the west coast, Tertiary rocks have been pierced in bores below Perth. It is quite possible that they are more widely distributed below the South-West Coastal Plain.

5. A belt of Tertiary rocks extends from somewhere north of Carnarvon in the North-West Division as far as Northwest Cape. It is about 200 miles long and on

[54] F. Chapman, "On Fossiliferous Grits and Cherts, Associated with the Nullagines of Western Australia," *Proc. Roy. Soc. Victoria*, Vol. 46 (1933), pp. 60–65.

[55] A. B. Walkom, "Fossil Plants from Gingin, W. A.," *Jour. Roy. Soc. Western Australia*, Vol. 29 (1942–1943), p. 201. 1944.

[56] F. A. Singleton, "The Tertiary Geology of Australia," *Proc. Roy. Soc. Victoria*, Vol. 53 (1941), pp. 1–125. This excellent summary has been used freely in the preparation of this chapter.

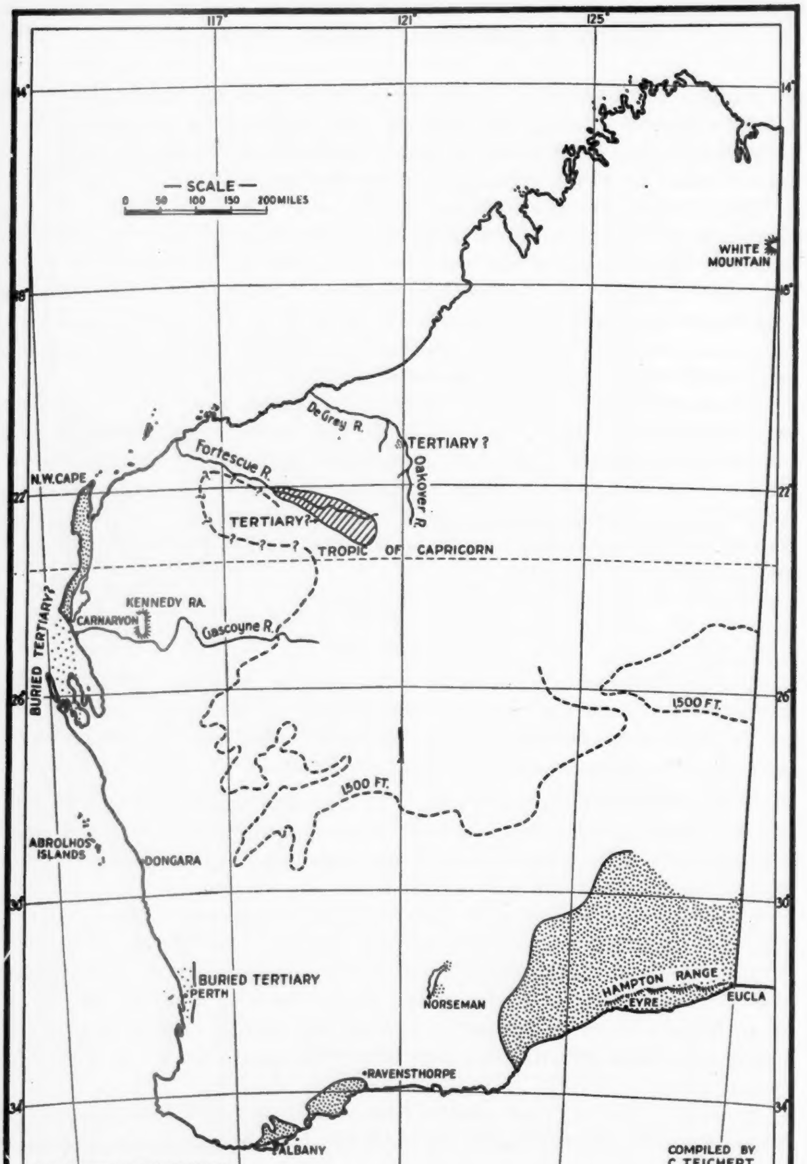

FIG. 21.—Distribution of Tertiary rocks. *Dense stippling:* outcrop areas; *wide stippling:* buried Tertiary; *oblique ruling:* Fortescue River basin. The 1500-foot contour (adapted from Contour Map of Western Australia, South Sheet, 1913) may indicate the approximate northern limit of the Miocene submergence of the Western Australian shield. North of the Tropic of Capricorn insufficient data are available to continue the line.

the average about 20 miles wide. However, there may be Tertiary outliers in this vicinity as far as 100 miles inland.

6. Lacustrine beds in the East Kimberley and North-West Divisions of doubtfully Tertiary age.

SUCCESSION

Considering the great differences in stratigraphy between most of the aforementioned areas, it seems best to discuss the succession in each area first, before a summary of Tertiary stratigraphy of the state can be given.

1. *Nullarbor Plain.*—The Nullarbor Plain is one of the most remarkable geological and physiographical features of Western Australia. It is a limestone plateau which rises imperceptibly from the coastal escarpment inland and which appears perfectly level when traversed on the ground. From the air very slight large-scale buckling and faintly indicated drainage patterns, too faint to be recognizable from the ground, may be seen here and there. The area of the Western Australian part of the Nullarbor Plain may be estimated as between 20,000 and 25,000 square miles. The nature of the country may be visualized from the fact that one section of the Trans-Australian Railway crosses the Nullarbor Plain in a perfectly straight line for 330 miles—the longest straight stretch of railway in the world.

The surface of the plateau is formed by limestone which breaks off toward the south in a steep escarpment about 200 to 250 feet high, known as "Hampton Range." This escarpment forms the coast southwest of Eyre, but from Eyre it bends away from the coast and extends in a slight northerly curve as far as Eucla on the South Australian border. Here it reaches the coast again and continues into South Australia.

The plain is almost completely treeless. Much of it is covered with low salt bush, but some parts are quite desert-like. Although the area receives several inches of fairly reliable rainfall per year there is no surface drainage, most of the water disappearing below the surface through cracks in the limestone.

This limestone is known as Eucla limestone. It is in general very fossiliferous and contains in places large numbers of bryozoans, pelecypods, and gastropods. Unfortunattely, the state of preservation of the fossils is generally discouraging and the fauna has never been studied in detail. Most of the fossils are preserved as internal molds only and identification is thus made difficult.

From the nature of the terrane it may be concluded that only a small thickness of beds is accessible in outcrops in the entire area of the Nullarbor Plain, and, in the absence of erosion channels and other natural excavations (other than caves which are as yet very incompletely explored), knowledge of the vertical section of the Eucla limestone is derived from the few bores which have penetrated it. From these it seems that the limestone is of very uniform composition throughout and that along a north-south section at 127° E. Long. its thickness increases from about 485 feet near the railway line to more than 900 feet at the Hampton Range escarpment.

Although no paleontological work has been done on the Western Australian side, the eastward extension of the Eucla limestone is a little better known and its Miocene age has been established in South Australia. Singleton believes that the Eucla limestone may range downward into the Oligocene.

Of considerable interest is the occurrence of reef-building corals near Forrest only 50 miles inside Western Australia on the railway line west of the South Australian border. This apparently indicates an influx of northwestern faunas into this area, but unfortunately the occurrence has not yet been investigated in the field. Specimens were collected and sent to the writer by members of the Royal Australian Air Force stationed there during the War.

2. *Norseman area.*[57]—Tertiary rocks occur in depressions near Norseman and in the general vicinity of Lake Cowan. These are no doubt remnants of a sheet of sediments which was once continuous with the Tertiary sediments in the east and in the southwest. Norseman is a mining center, situated 350 miles east of Perth and more than 100 miles north of Esperance on the south coast. It lies well inside the Great Western Australian Plateau of pre-Cambrian rocks, near the southern end of Lake Cowan, one of the major "salt lakes" of the state. Like other Western Australian "lakes," Lake Cowan has a perfectly level floor, most of which is covered with a deposit of salt mud. The "lake" is ordinarily dry, although a few inches of rapidly evaporating water may accumulate after heavy rains in the winter. (Fig. 22, insert of photographs.)

Three main rock types are known which occur in scattered outcrops on the floor and along the shores of Lake Cowan: fossiliferous limestone, non-fossiliferous dolomites, and sponge-spicule beds.

The limestones (in places dolomitized) contain a fairly rich fauna, mainly bryozoans, pelecypods, and gastropods of Middle Miocene age and of eastern Australian affinities. The sponge-spicule beds are commonly soft sandstones with a varying amount of sponge spicules which include a great variety of monactinellid, tetractinellid, and lithistid types. In places these spicules make up the bulk of the rock which may then be known as spiculite or spongolite. The best known occurrence of this lock type is near the (now abandoned) townsite of Princess Royal 4½ miles north of Norseman, where these beds are well exposed in a depression in the pre-Cambrian. Their thickness is little more than 20 feet. Nowhere do the Tertiary strata in this area seem to exceed 50 feet in thickness.

3. *South coast west of Ravensthorpe.*[58]—This belt of Tertiary sediments, known as Plantagenet series, begins on the coast approximately south of Ravensthorpe and extends westward as far as Albany, the principal harbor on the south coast. The rocks are silts and fine-grained sandstones, in places rich in sponge spicules and not unlike some of the Lake Cowan spongolites already mentioned. They

[57] E. de C. Clarke, C. Teichert, and J. McWhae, "Tertiary Deposits of the Norseman Area, Western Australia," *Jour. Roy. Soc. Western Australia* (in press, 1946).

[58] F. Chapman and I. Crespin, "The Palaeontology of the Plantagenet Beds of Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 20 (1934), pp. 103–36.

rest in patches on pre-Cambrian granite which forms the coastal cliffs in many places. Their maximum thickness is not exactly known, but may be approximately 200 feet. In addition to sponges, the strata contain a rich fauna of pelecypods and gastropods as well as bryozoans, echinoids, brachiopods, cephalopods, and plant impressions. Chapman and Crespin determined the age of these beds as Lower Miocene, but Miss Crespin has informed the writer that she now regards them as Middle Miocene, that is, of the same age as the Norseman limestones.

It may be assumed that the Plantagenet series was once continuous with the Tertiary deposits near Norseman and that the intervening cover of sediments has been removed by Upper Miocene and post-Miocene erosion.

4. *South-West Coastal Plain.*—Many deep bores have shown the South-West Coastal Plain to be underlain by a considerable thickness of sediments. In places these have been proved to be Jurassic and Cretaceous, as already described, but in places they are younger. The only place where the presence of buried sediments of Tertiary age has been proved by paleontological evidence is the section below Perth.[59] The thickness of sediments below the Coastal Plain is here known to be in excess of 2,000 feet. The rocks are mostly sandstone and shale and Eocene Foraminifera have been recorded in cores from depths between 120 and 780 feet. More recently, a richly fossiliferous black shale has been found at a depth of 60 to 100 feet below sea-level at Government Garden, Perth, but its fauna has not yet been studied. From the study of a few Foraminifera Miss Crespin suggests an Eocene age, but considering its high position in the sequence, it might well be somewhat younger.

It is quite possible that Tertiary strata have a wider extent below the Coastal Plain north of Perth, but nothing definite is known at present. However, it might be well to be reminded at this stage that the Coastal limestone of Pleistocene age has often been classified as Tertiary and that, therefore, "Tertiary" is mentioned from the South-West Coastal Plain in a number of geological reports.

5. *North-West Division.*—The most complete Tertiary sequence in Western Australia is known from the coastal country north of Carnarvon between approximately 24° 20′ and 21° 40′ S. Lat. These beds form low coast ranges or coastal platforms and near the northern end of the belt they are thrown into low anticlinal structures, of which Rough Range and Cape Range, extending as far as Northwest Cape, are examples. (Figs. 23 and 24, insert of photographs.)

The oldest rocks in this belt are Upper Eocene in age. They are known from Cape Cuvier and Red Bluff, 40 to 50 miles north of Carnarvon, as well as from the vicinity of Giralia, south of Exmouth Gulf. The rocks are foraminiferal and bryozoan limestones, commonly with rolled quartz grains; at least in the Giralia anticline, they do not seem to be more than 30 feet thick. Characteristic foraminif-

[59] W. J. Parr, "Upper Eocene Foraminifera from Deep Borings in King's Park, Perth, Western Australia," *Jour. Roy. Soc. Western Australia*, Vol. 24 (1937–1938) pp. 69–101. 1938.

eral genera in these beds are *Discocyclina*, *Pellatispira*, *Asterocyclina*, and *Nummulites*. Singleton has given the name Giralian to this series.

Next younger in the sequence seem to be limestones with *Lepidocyclina dilatata*, *L. papuanensis*, and *L. chapmani*, whose age has been somewhat disputed. At first they were determined by F. Chapman[60] as Oligocene, but a few years later the same author[61] seems to have changed his opinion and to have referred the same beds to the Lower Miocene. In the same way, Irene Crespin, in 1938[62] seems to be inclined to stress the Lower Miocene affinities, but Singleton in 1941[63] pointed out that *C. papuanensis* was known from Tertiary *d* in East Borneo and consequently he referred the rocks in question back to the Upper Oligocene.

Of unquestionable Miocene age are limestones with *Lepidocyclina murrayana* and *L. insulaenatalis*, associated with nephrilepidines and with *Cycloclypeus*. Still higher in the Miocene are limestones with *Marginopora vertebralis*, *Flosculinella bontangensis*, *Trillina howchini*, and nephrilepidines, which in turn are overlain by white coralline limestones which may range upward into the Pliocene.

The entire Tertiary sequence is possibly not more than 700 feet thick. Its fauna shows close affinities to the East Indian Tertiary and the following correlations between the East Indies and Western Australia have been suggested.

East Indies		*Western Australia*
Pliocene	h g	?Coralline limestone
Miocene	f	Limestones with *Trillina howchini*, *Flosculinella bontangensis*, *et cetera*
	e	Limestones with *Lepidocyclina murrayana*, *L. verbeeki*, *et cetera*
Oligocene	d c	Limestones with *Lepidocyclina dilatata*, *L. papuanensis*, *et cetera*
Eocene	b	Limestones with *Discocyclina and Pellatispira* ("Giralian")
	a	

Tertiary rocks, though at present best known from a narrow coastal belt, must be present much farther east, at least as far as 100 miles or so inland[64] for specimens of Miocene *Aturia clarkei* and a small associated fauna have been found on the east side of the Kennedy Range, north of the Gascoyne River.

6. *Lacustrine beds of doubtful age.*—No marine Tertiary beds are at present

[60] F. Chapman, "On a Limestone Containing Lepidocyclina and Other Foraminifera from the Cape Range, Exmouth Gulf, W. A.," *Proc. Roy. Soc. Victoria*, Vol. 39 (1927), pp. 125–48.

[61] Footnote in D. D. Condit, "Oil Possibilities in Northwest District, Western Australia," *Econ. Geol.*, Vol. 30 (1935), p. 865.

[62] I. Crespin, "Tertiary Rocks in North-West Australia," *Rep. Aust.N. Zeal. Assoc. Adv. Sci.*, Vol. 23 (1938), p. 443.

[63] F. A. Singleton, "The Tertiary Geology of Australia," *Proc. Roy. Soc. Victoria*, Vol. 53 (1940), p. 12.

[64] C. Teichert, "The Genus *Aturia* in the Tertiary of Australia," *Jour. Paleon.*, Vol. 18 (1944), pp. 73–82.

known from anywhere north of Northwest Cape, and non-marine occurrences are not undisputed. E. T. Hardman, in 1884, discovered a small occurrence of fossiliferous chert in the East Kimberley Division near the Trigonometrical Station J40 in a small range known as White Mountains[65] and this bed was usually regarded as of Upper Tertiary age until Chapman described its fauna more fully in 1937.[66] This includes *Planorbis hardmani, Planorbis* cf. *essingtonensis, Bullinus* sp., as well as remains of Foraminifera, sponges, ostracodes, and insect and plant fragments. Chapman concluded that these beds, in common with similar deposits in Central Australia and Queensland are Pleistocene.

More recently[67] it has been shown that these lacustrine beds are much thicker than was previously known and that they cover an appreciable area in the White Range southeast of Trigonometrical Station J40. The sequence is here as follows.

	Feet
Planorbis chert	5
Siltstone	10
Chert	30
Siltstone	55
Marl	215
Siltstone with basal chert	55
Total thickness	370

The whole series is slightly folded and east of the Trigonometric Station, where the most complete series was observed, it dips at 25° NE. These observations seem to support Singleton's suggestion that the "physiographical setting" of the beds may indicate a Pliocene rather than a Pleistocene age. (Fig. 25, insert of photographs.)

A large area of sandstones, limestones, and cherts of moderate thickness is known from the valley of the Oakover River (abt. 21° S. Lat.) in the North-West Division where they rest with a violent unconformity on the Nullagine system. The beds have been strongly eroded and form steep escarpments and isolated mesas. No fossil evidence is available to support the correlation of the Oakover beds with the Tertiary, and as the occurrence is not so far from the southeastern edge of the Desert basin of Paleozoic rocks, they might well be older.

A very much larger area of relatively young sediments occupies a sunkland through which the Fortescue River flows in its upper course between the Hamersley-Ophthalmia Plateau in the south and the Northern Plateau in the north. More than 3,000 square miles of this sunkland are covered with sediments which range from fine silt to pebble beds. Their thickness is unknown, but exceeds 100 feet.[68] They are believed to be lake deposits and may reasonably be

[65] Hardman, Wade, and others refer to this range as "Mt. Elder Range." Mt. Elder, however, is a hill quite separate from the line of the White Mountains.

[66] F. Chapman, "Cherty Limestone with Planorbis from the Mount Elder Range, Western Australia," *Proc. Roy. Soc. Victoria*, Vol. 50 (1937), pp. 59–66.

[67] C. Teichert and R. S. Matheson, "Geological Reconnaissance in the Eastern Portion of the Kimberley Division, Western Australia," *Geol. Survey Western Australia, Ann. Progr. Rept. 1945*. Perth (1946).

[68] H. W. B. Talbot, "The Geology and Mineral Resources of the North-West Central, and Eastern Divisions," *Geol. Survey Western Australia Bull. 83* (1920), pp. 1–217.

expected to be younger than Miocene, though it is impossible to state at present whether they are Pliocene or Pleistocene in age.

Of somewhat similar age are possibly the Brumby Creek beds in the valley of the Ashburton River farther south (about 119° E. Long., 24° 15′ S. Lat.) The limestones with chert bands are probably lacustrine in origin.

SUMMARY OF TERTIARY PALEOGEOGRAPHY

During the Paleogene almost all of Western Australia must have been above sea-level, since Upper Eocene and, probably, Upper Oligocene limestones are restricted to a narrow belt near the coast of the North-West Division, and since there is no indication of a former wider distribution of such rocks.

It was first during the Miocene that a considerable part of Western Australia was submerged. The amount of the submergence may have been approximately 1,500 feet below the level at present occupied by this part of the continent, and the present 1,500-foot contour may therefore give a rough idea of the position of the coast line at that time. Deposits of this sea are the Eucla limestone, the Plantagenet beds, the Norseman limestones and spongolites, foraminiferal limestones of the North-West Division, and the *Aturia* beds of the Kennedy Range. It is quite possible that additional sedimentary outcrops will be found in salt lakes and other depressions of the North-West and Eastern Divisions.

At the end of the Miocene, perhaps already in Upper Miocene time, the land emerged again and the sea withdrew and probably continued to cover but insignificant parts of the continent. The following Pliocene was of great importance for the evolution of the present topographical features of large parts of Western Australia because it was most likely during this time that an almost continuous laterite layer was formed, probably as a hard-pan under humid conditions.[69] This layer which is also called "duricrust" in Western Australia has been much eroded since Pliocene time, but it still covers considerable parts of the North-West, South-West, and Eastern Divisions, and even where the cover is not continuous now, there are numbers of eroded remnants to be found. The effect of the presence of this rather resistant cover is that much of the bedrock in these areas is concealed and the study of the geological structures is rendered difficult.

It is possible that the sedimentary filling of some of the salt lakes dates back to Tertiary time (see under "Pleistocene").

TERTIARY VOLCANISM

Western Australia seems to have been entirely free from any signs of volcanic activity from early Paleozoic until Tertiary time. The volcanic rocks that are supposed to belong to the latter period may therefore receive a brief mention.

In the far southwest part of the state there is a small basalt occurrence at Bunbury which is older than the Pleistocene Coastal limestone. From its occurrence on the coast where it is now being strongly eroded by the ocean waves, it

[69] See E. de C. Clarke, R. T. Prider and C. Teichert, *Elements of Geology*, pp. 47–50. Perth (1944).

may be concluded that its eruption perhaps did not precede the formation of the Coastal limestone by a very long time and that the basalt is not older than Late Tertiary. A few basalt occurrences presumably of the same age are found along a line south of Bunbury as far as the south coast.[70]

Another area of comparatively young volcanism is found in the West Kimberley Division where the Permian rocks are pierced by numerous plugs of leucite rocks of highly exceptional composition.[71]

Most of these form conspicuous physiographical features standing out as cones or sharp-crested hills above the sedimentary plains surrounding them. From their youthful appearance it seems unlikely that they should be of any considerable age and they are probably not older than Late Tertiary.

PLEISTOCENE[72]

Deposits of Pleistocene age must have a wide distribution in Western Australia, but on the whole little attention has been paid to them; in many places their age might not have been recognized; and in places they may be difficult to differentiate from Recent deposits. The following survey of Pleistocene sediments of Western Australia is, therefore, very incomplete, but as rocks of this age may reach appreciable thicknesses they must not be neglected. These rocks are best considered in three major groups according to their origin: (1) marine (2) eolian, and (3) lacustrine and fluviatile.

1. *Marine deposits.*—The coast of Western Australia from the extreme southwest northward at least as far as Port Hedland, but probably farther north, is lined with a narrow and discontinuous belt of limestones and well bedded calcareous sandstones which in some places are richly fossiliferous. The fossil assemblages in these rocks bear a strong resemblance to the recent faunas along the same coast although in some places they seem to contain species that are not now known to occur at the same latitude. Well known shell deposits are those along the Swan River in the vicinity of Perth (Peppermint Grove, Minim Cove, and others) which rise to 23 feet above sea-level and contain some species of mollusks which at present do not occur south of Geraldton, 250 miles north.

In Perth limestones have been pierced by bores down to a depth of 180 feet below sea-level,[73] and it seems reasonable to conclude that these deeper limestones are at least partially marine, even though it is known that in places the overlying eolian limestones reach below sea-level.

[70] A. B. Edwards, "Tertiary Tholeiite Magma in Western Australia," *Jour. Roy. Soc. Western Australia,* Vol. 24 (1937–1938), pp. 1–12. 1938.

[71] A. Wade and R. T. Prider, "The Leucite-Bearing Rocks of the West Kimberley Area, Western Australia," *Quar. Jour. Geol. Soc. London,* Vol. 96 (1940), pp. 39–98.

[72] Western Australian deposits of Pleistocene age, particularly those of marine and of eolian origin, have sometimes been classified as Tertiary; sometimes they have been included with Recent or "sub-Recent" deposits.

[73] F. G. Forman, "Final Report on the Correlation of the Artesian Bores in the Metropolitan Area," *Geol. Survey Western Australia, Ann. Progr. Rept. 1932* (1933), pp. 9–10.

Contemporaneous deposits are probably the shell beds at the bottom of the Swan River estuary which occur at a distance of up to 8 miles from the present coast and which contain a rich fauna of Recent species such as *Ostrea angasi*, *Chama limbula*, *Gafrarium sulcatum*, *Dosinia sculptilis*, *Chlamys asperrimus*, *Polinices conicus*, and many others.[74]

Elsewhere small coral reefs occur in the same beds. Two studied by the writer are the Leander Point Reef at Denison 40 miles south of Geraldton and a reef in Salmon Bay on the south coast of Rottnest Island, off the mainland coast at Fremantle. Both reefs are flat-topped and rise to about 10 feet above mean sea-level. The association of reef corals in both is very much like that now found in the Abrolhos Islands, although one is 30 miles, the other 200 miles, south of the southernmost coral island of that group. There are small colonies of reef corals, too small to be called coral reefs, much farther south along the coast as far as Canal Rocks, 10 miles south of Cape Naturaliste (about 33° 50′ S. Lat.). In the North-West Division are similar fossiliferous limestones in the vicinity of Cardabia Station near Maud Landing and near Yardie Creek, 50 miles south of North- West Cape. Here these limestones contain the tropical mollusk fauna characteristic of these latitudes at the present day.

The aerodrome of Onslow (about 23° 40′ S. Lat.) in close proximity to the coast and only 1–2 feet above high water level (about 9 feet above mean sea-level) is built on the surface of an emerged coral reef, but this is of course well inside the tropical reef belt of the present day. A bore near the township of Onslow penetrated solid limestone from 30 to 214 feet below sea-level, before entering a thick shale section of more than 1,500 feet. Thus, it is most likely that the marine Pleistocene limestone in this general area is 180 to 220 feet thick. Little is known about the distribution of this limestone farther north, but it may occur as far north as the west coast of Dampier Land, north of Broome.

In most places this marine limestone belt is narrow, but where the coastal country is very flat or where embayments existed, they might be found up to a few miles inland from the coast. Thus, at Cardabia and at Perth the limestone occurs several miles from the present outer coast.

The core of older coral reefs in the four main groups of the Abrolhos Islands, 40 miles off the coast opposite Geraldton in the Indian Ocean, also belongs to this same limestone formation. The top of these old reefs is now generally 6 to 12 feet above mean sea-level.[75] (Fig. 26, insert of photographs.)

It seems very probable that much, if not most, of the continental shelf along the west coast is covered by limestone deposis of the same age. It has already

[74] J. L. Reath, "Mollusca from the Sub-Recent Shell-Beds of the Lower Swan River," *Jour. Roy. Soc. Western Australia*, Vol. 11 (1925), pp. 31–41.

[75] C. Teichert, "Contributions to the Geology of Houtman's Abrolhos, Western Australia," *Proc. Linn. Soc. New South Wales* (in press, 1946). It should perhaps be mentioned that the coral islands of the Sahul Shelf, off the northwestern coast of the Kimberley Division, are of an entirely different type. The writer has examined aerial photographs of Seringapatam Reef, Cartier Reef, Browse Island, and Adele Island and found that none of them has any emerged reef limestones. They are similar to some reefs of the inner belt of the Great Barrier Reef of Queensland which were examined early in 1945.

been mentioned that the thickness of the limestone is in the vicinity of 200 feet in such widely separated places as Perth and Onslow, which is not likely to be a mere coincidence. On Rottnest Island, 12 miles off the coast west of Fremantle 210 feet of limestone were found in a bore below 20 feet of superficial sand, but elsewhere on the island the same limestone crops out above sea-level. There is thus evidence that the continental shelf, at least down to the 35-fathom line, is covered with a considerable deposit of Pleistocene limestones. Not all of these submerged limestones, however, may be marine; some may belong to the eolian group to be discussed next.

All these rocks are older than the eolian limestones which, as shown in subsequent paragraphs, are not younger than late Pleistocene. It is reasonable to assume that the marine limestones were formed during an interglacial period of the Pleistocene, when the climate was slightly warmer and the sea-level stood somewhat higher than at the present day. They may be deposits of either the Mindel-Riss or of the Riss-Würm interglacial stage.

The Mindel-Riss Interglacial was probably the longer of the two and at times its climate was warmer than of the present day. The marine coastal limestones may therefore well have been formed during this stage.

The fact that they are now exposed above sea-level is chiefly due to the negative eustatic 5-meter shift of sea-level in mid-Recent time for which there is abundant evidence elsewhere in Australia and in the South-West Pacific area.[76]

2. *Eolian deposits.*—In close association with the marine limestones occur dune limestones which form a very conspicuous physiographical feature along something like 1,500 miles of coast in Western Australia. These eolian limestones are generally referred to as "Coastal limestone," a term in which the underlying marine section may or may not be included. They form a belt as much as 6 miles wide, though in most places narrower, extending from Bremer Bay on the south coast (about $119\frac{1}{2}°$ E. Long.) westward around the southwestern corner of the continent and northward along the west coast as far as North-West Cape. Farther north they seem to be very scattered, though the writer has observed dune limestone hills from the air several miles northeast of Port Hedland (about 20° 20′ S. Lat.) and there seems to be some evidence for them as far north as Cape Villaret, 25 miles south of Broome and the west coast of Dampier Land, north of Broome. But even in the south, along the west coast between Cape Leeuwin and Northwest Cape, the dune limestone belt is by no means unbroken, although it has never been completely mapped and large parts of it have probably not been seen by geologists. Some areas of outstanding development of dune limestone topography are the following.

(1) The pre-Cambrian ridge between Cape Leeuwin and Cape Naturaliste where there are large caves in the Coastal limestone. In deposits laid down in these caves numerous remains of extinct marsupials have been found which in-

[76] W. R. Browne, "An Attempted Post-Tertiary Chronology for Australia," *Proc. Linn. Soc. New South Wales*, Vol. 70 (1945), pp. V–XXIV.

clude *Diprotodon, Nototherium,* the Tasmanian Devil, the Marsupial Lion, the Koala Bear, extinct giant Kangaroos, and others, though these must belong to a somewhat later time, perhaps very late Pleistocene or very early Recent.

(2) The vicinity of Perth (King's Park, Mosman Park, *et cetera*) and the outlying islands, Rottnest, Garden Island, and others. In many places the dune limestones can be seen cropping out at sea-level, for example, on the east coast of Rottnest Island where they are now subjected to wave erosion.

(3) Separated from this locality by almost 300 miles of mostly exceedingly monotonous coast line are thick dune limestone deposits north of the Bowes River, about 30 miles north of Geraldton. Between Perth and the Bowes River there are a great many occurrences of smaller limestone cliffs, probably at least partly of eolian origin. The coast is fringed by many limestone shoals, reefs, and islets which make it dangerous to navigation. The writer has frequently flown along this coast but in only a very few places has it ever been visited by geologists.

(4) Dune limestones up to 40 feet thick are found on the larger islands (East and West Wallaby, and North Island) of the Abrolhos Island group. They overlie the Pleistocene reef limestones already mentioned and are now everywhere dissected by marine erosion.

(5) High dune limestone ridges seem to be present along the coast north of about 27° S. Lat. on Tamala[77] and on the peninsula separating Freycinet Bay from the Indian Ocean; from here the limestone belt probably continues across South Passage to Dirk Hartog Island where it rises to 608 feet above sea-level. No part of this coast has been examined by geologists.

In many places and along certain horizons the dune limestones are penetrated by a mesh-work of root-like structures which are the calcareous fillings of cavities left by roots of plants. Periods of fixation of the old dunes are thus evident. Everywhere, of course, the limestones are very strongly false-bedded.

In some localities these limestones occur in places where it would have been impossible for them to be formed under physiographic conditions resembling those of the present day. This is especially true for the dune limestones of the Abrolhos Islands and it is most likely that all these eolian limestones were formed during a glacial stage of the Pleistocene, when the sea-level stood lower than now and large parts of the Western Australian shelf were exposed to wind erosion. The Western Australian shelf varies in width from a few to 50 to 60 miles and its average depth below sea-level is now 20 to 25 fathoms. It must, therefore, have been dry land repeatedly and for a prolonged period during the Pleistocene. The evidence about the origin of the Western Australian dune limestones thus agrees well with that proposed for similar deposits in Victoria, Bermuda, and elsewhere.[78]

[77] In this vicinity the British Admiralty Chart (1056) notes "high sandstone cliffs" of 850 and 1,000 feet. Seen from the air at a distance of 20 to 30 miles these ridges rise conspicuously above the general level of the plateau, so that the writer has little doubt to interpret them as dune limestone. The heights given in the Admiralty Chart may, however, be somewhat exaggerated.

[78] E. S. Hills, "The Age and Physiographic Relationships of the Cainozoic Volcanic Rocks of Victoria," *Proc. Roy. Soc. Victoria*, Vol. 51, Pt. 1, N.S. (1939), pp. 125–28.

As mentioned, caves in these limestones contain deposits with extinct marsupials which are generally regarded as Pleistocene, though they may be early Recent in age. The dune limestones themselves, therefore, can not be younger than late Pleistocene.

The fact that in many places the transition from the underlying marine limestones to the dune limestones is gradual, suggests that the latter must have been formed during the glacial stage immediately following that inter-glacial stage in which the marine limestones were laid down, probably the Riss, or possibly the Würm stage. The material for the dune limestones must have been largely derived from the underlying marine limestones which, as has been shown, appear to cover large parts of the continental shelf, where they were exposed when the sea level was lowered.

Consolidation of the calcareous sand dunes was caused by rain water. Similar processes of consolidation in recent dunes are going on today in many places along the coast.

3. *Lacustrine and fluviatile deposits.*—As has already been mentioned, it is quite possible that some of the lacustrine deposits described in the previous chapter as possibly Tertiary might actually be Pleistocene. In some cases, investigations into the microfauna or flora of these beds may aid in the determination of their age, but such studies have not yet been undertaken in Western Australia.

The fillings of many lake basins in the North-West, Eastern, Central, and South-West Divisions are possibly Pleistocene in age, but little is in general known about these sediments. In the southern part of Lake Cowan, near Norseman, "bituminous" silt and clay have been reported in a bore to a depth of 377 feet below the level of the lake. In some, as in Lake Campion, a mud containing 60 per cent of alunite was deposited. In this connection the "deep leads" of the Western Australian Plateau may be mentioned most of which were apparently formed after the post-Miocene period of uplift, though probably not all at the same time. Some may even antedate the Miocene, for example, the Princess Royal deep lead near Norseman where gold was obtained from below the Miocene sponge-spicule sandstones. These occurrences can not be described in detail in the present paper and it must suffice to refer to published accounts.[79]

Small occurrences of marl deposits are known from many places in the South-West Coastal Plain, some of them containing fresh-water gastropods, though these deposits may be early Recent in origin.

SYNOPSIS OF SEDIMENTARY AREAS

Sedimentary sequences reflect the tectonic behavior of crustal units. They bear witness not only of the tectonic movements of the area of accumulation but also to a certain extent of the behavior of adjacent landmasses that supplied the

[79] J. T. Jutson, "The Physiography (Geomorphology) of Western Australia," *Geol. Survey Western Australia, Bull. 95* (1934), pp. 208–12.
E. de C. Clarke, R. T. Prider, and C. Teichert, *Elements of Geology*, pp. 285–86. Perth (1944).

sediments. From this point of view we arrive at the following classification of sedimentary areas in Western Australia.

1. Scattered outcrop areas
2. Large, comparatively thin sheets of sedimentary rocks
3. Coastal basins
4. Major sedimentary basins

1. *Scattered outcrop areas.*—Here are grouped scattered and mostly small areas of sediments resting on a pre-Cambrian basement. Thicknesses measure in hundreds of feet or even less. This is a rather inhomogenous group of outcrop areas which, however, may be considered together here, because they are not of great importance in the general structure of Western Australia.

Firstly, there are outcrops that are remnants of a once larger sheet of sedimentary rocks, most of which has been eroded away. Typical examples are the Tertiary sediments on the pre-Cambrian in the southern part of the Western Australian shield (Plantagenet beds, Norseman limestone, *et cetera*) and the many outcrops of sandstones and boulder beds of possibly Cretaceous age (outlines of the Wilkinson Range beds) that are found on the pre-Cambrian shield from the Ponton River in the south to Lake Carnegie in the north, that is, an area of 60,000–70,000 square miles. These sediments are of greatly varying (mostly unknown) thickness which perhaps nowhere greatly exceeds 200 feet. In places the thickness dwindles to a few feet as in the case of the Miocene limestones on the bed of Lake Cowan. All these sediments are of very great paleogeographical interest, because they indicate short temporary *en bloc* submergences of large parts of the pre-Cambrian shield. Adjacent areas on the east were similarly submerged, but did not rise again to their previous level.

A second category in this group are isolated outcrop areas which have been preserved through downfaulting. There are few examples of this type in Western Australia. The best known is the Collie coal basin in the extreme southwest part of the state, about 100 square miles large and entirely surrounded by pre-Cambrian granites. The thickness of the beds here is not exactly known, but must be upward of 2,000 feet and the general geological setting suggests that the margins of the basin are faulted. Similar basins might be present in this vicinity. The Collie basin is situated well inside the pre-Cambrian shield, about 20 miles from its western margin which breaks off in a 700-foot scarp toward the Coastal Plain. Of possibly tectonic origin is also the low country between the western margin of the shield and the ridge of pre-Cambrian rocks that extends between Cape Leeuwin and Cape Naturaliste, and which is underlain in its northern part by at least 1,000 feet of sandstones and shales. However, this area might be a southern continuation of the South-West Coastal basin.

Last in importance among the scattered outcrop areas are sediments that have been laid down in disconnected basins. There are many of them scattered all over the Western Australian shield, but only few of them are of appreciable size.

The largest no doubt is the Fortescue River basin with an unknown thickness

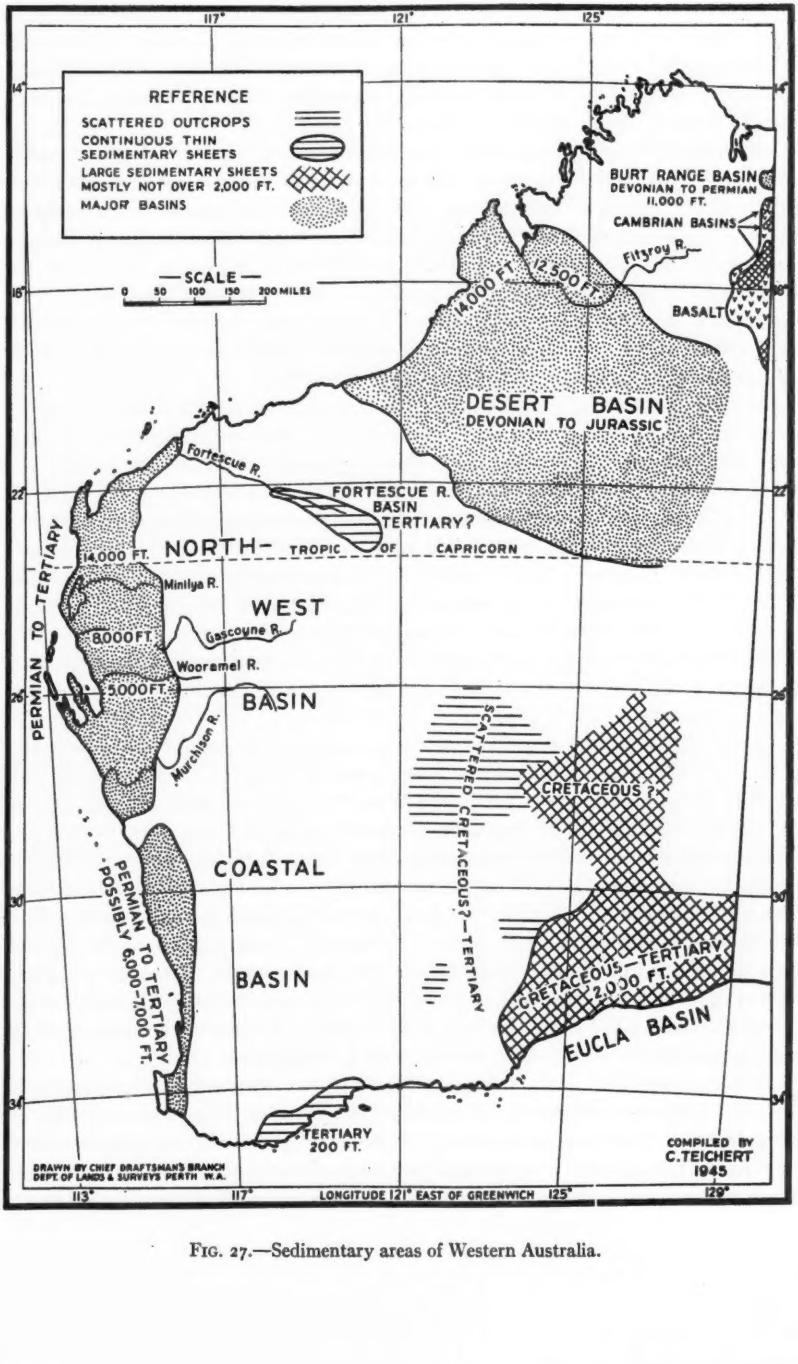

FIG. 27.—Sedimentary areas of Western Australia.

of possibily Tertiary sandstones. Next in importance are perhaps the sediments of the Oakover River, variously referred to the Permian, Cretaceous, Tertiary, and Pleistocene, though very little is actually known about them. The Tertiary, (?) Pleistocene, and Recent sediments of the many salt lakes of Western Australia are also to be included in this category.

2. *Sheets.*—These are sediments spread out in large "sheets," either undisturbed or only slightly deformed. Thicknesses range up to a few thousand feet, but are small compared with the size of the "sheets." Typical are the Cretaceous-Tertiary sediments of the Nullarbor Plain whose thickness only slightly exceeds 2,000 feet. Here sandstones and shales of Cretaceous age are overlain by the Miocene Eucla limestone. The attitude of the beds over an area of probably more than 25,000 square miles, is practically horizontal, probably with an imperceptible dip toward the coast, and with large-scale warpings having an amplitude of several miles and a height of not more than a few feet.

After the formation of the sediments in this area the pre-Cambrian basement remained at such a level that the bulk of the sediments escaped erosion, even if some elevation did take place. A similar area might be that covered by the Wilkinson Range beds farther north, in the interior of the Eastern Division.

To this category also belongs the Cambrian of the East Kimberley Division. Here it is the Lower Cambrian basalt which covers huge tracts (extending into the Northern Territory) like a blanket which has been thrown into broad folds. Remnants of the overlying sedimentary series of Lower and Middle Cambrian age are preserved in the basins, although they are not entirely absent from the domes. This area occupies a somewhat unique position because of the thick sheet of basalt which is intercalated between the pre-Cambrian below and the sediments above.

3. *Coastal basins.*—Narrow coastal strips underlain by an unknown, but probably great, thickness of sediments. Known thicknesses are a few thousand feet. The best known example is the South-West Coastal basin between 33° 40′ and 28° 50′ S. Lat. It is almost 350 miles long and 10 to 30 miles wide. On the east side it is bordered by the western margin of the Great Western Australian Plateau whose gneisses and granites rise rather abruptly to a height of several hundred feet above the coastal plain. In the west the coastal plain merges into the continental shelf which is generally 20–30 miles wide, widening to about 60 miles toward the north and south. Coastal Plain and shelf may be regarded as one geological unit, because only very slight variations in sea-level would enlarge either at the expense of the other. Unfortunately, little is known of the geology of the continental shelf, except along the coast off Fremantle.

The South-West Coastal basin contains Permian, Jurassic, Cretaceous, Tertiary, and Pleistocene rocks much of which are concealed under a cover of Recent sand deposits. In several places the strata underlying the Coastal Plain have been pierced by bores down to 2,500 feet and beds of various ages have been found. Near its northern end the Dongarra and Yardarino bores, traversing sediments

down to a depth of 2,100 feet, might have reached Jurassic rocks, but probably did not strike the Permian which crops out 20 to 30 miles inland. The Moora Bore, 100 miles farther south, penetrated 1,150 feet of Jurassic and continued to a depth of 2,230 feet in what are probably Permian sandstones and shales. Deep bores below Perth have proved the presence of more than 2,000 feet of Tertiary and probably Cretaceous sandstones and shales, and on Rottnest Island, 12 miles off the coast in the same latitude, a bore was sunk to a depth of 2,582 feet, this being the only source of information about the beds underlying the continental shelf. A condensed record of the succession is as follows.

	Thickness in Feet
Superficial sand	20
Limestone	210
Sandstone and loose sand	1,075
Sandstone and shale	278
Shale and sandy shale	622
Sandstone and loose sand	273
Shale	174
Total	2,582

The age of these beds is unknown, though must be presumed to be mostly Tertiary, perhaps extending downward into the Cretaceous.

Farther south, in the Bunbury area, more than 1,000 feet of sediments that might be Permian in age were found.

Near the northern end of the Coastal basin (Irwin River district) Permian strata of more than 3,000 feet thickness occur. That this Permian belt once continued in a southern direction is suggested by the presence of the Collie and Wilga coal basins in the south. Its continuation under the Coastal Plain would seem likely even if the Moora Bore log did not suggest it. Thicknesses of the Jurassic as far as known from outcrops certainly exceed 1,000 feet and have been estimated to be as much as 2,000 feet. Cretaceous may not be expected to have exceeded a few hundred feet, but Tertiary, from evidence available from the Perth bores must at least locally be thicker than 1,000 feet. A total thickness of 6,000 to 7,000 feet of sediments below the Coastal Plain and the continental shelf is therefore entirely within the realm of possibilities.

No other structural units which are exactly comparable with the South-West Coastal basin are known in Western Australia. Conditions might be somewhat similar in the northern extension of the Northwest basin, where the sedimentary belt narrows considerably north of Onslow. At Onslow, 1,729 feet of sediments, mostly shales, have been found in a bore. These beds are probably an extension of the Cretaceous from the country farther south. North of Onslow geological conditions are unknown.

4. *Major basins.*—The last and most important class of sedimentary areas in Western Australia are the major basins of many thousand square miles and with thicknesses in excess of 10,000 feet. There are three of them in the state, one of which, the Burt Range basin, however, is only partly situated on Western Aus-

tralian territory. It might be well to describe this, the most recently discovered, first.

(a) *Burt Range basin.*—Although not comparable in size with the other two basins, it seems to contain a considerable thickness of sediments, but only the southernmost part of the basin is known at present and even this has only been superficially examined. The section in the vicinity of the Burt Range (near the Northern Territory boundary at about 15° 50′ S. Lat.) is as follows.

		Feet
Permian	Sandstones and conglomerates	1,000+
Carboniferous	Bryozoan limestone	350
Devonian	Sandstone series	1,000
	Fossiliferous limestones, calcareous sandstones and shales	4,000
	Sandstones and conglomerates (Cockatoo series)	4,800
	Total	11,150+

The area occupied by these rocks on the Western Australian side of the boundary is as far as known at present only a few hundred square miles. However, the country along the boundary north of 15° 40′ has never been geologically examined and from disconnected observations by surveying parties of the Lands Department of Western Australia it seems likely that much, if not all, of this country is underlain by sediments. Many maps showing the distribution of Artesian basins in Australia indicate a "Gulf basin" in this general vicinity, although the writer has been unable to discover on what evidence the assumption of this basin could have been based.

North of the Burt Range the sediments strike across the boundary into the Northern Territory in the direction of the Keep River and may continue in that direction as far as the Victoria River. An area of Permian sediments has long been known along the coast between the Victoria and Daly rivers in the Northern Territory. The fossils suggest beds with close affinities to the Nooncanbah and Wandagee series of Western Australia. It is possible that the Burt Range basin continues in this general direction and includes this or similar Permian areas.In this case one would expect that the thickness of the sequence should at least be maintained; however, at Port Keats and Anson Bay, near the coast between Victoria and Daly rivers, bores sunk in search for coal went through 1,500 feet of Permian and it is reported that they struck granite underneath,[80] so that it seems that the older sediments of the Burt Range section disappear in this direction. A broad regional survey of this area is urgently required. The size of the basin may be of the order of 15,000 square miles.

(b) *Desert basin.*—We now proceed from the almost unknown to the little known. It has already been pointed out that only a comparatively small part of the Desert basin has been investigated. Its northeastern marginal regions are best known; the position of the southwestern margin has been more or less fixed

[80] H. I. Jensen, "The Northern Territory," *Queensland Geogr. Jour.*, Vols. 22–23, N.S. (1916–1918), p. 111. (Reference by kindness of H. O. Fletcher of Sydney.)

but the succession here is practically unknown; the southeastern margin has never been seen by geologists and as shown on existing maps, including the ones in the present paper, it is entirely hypothetical. Although the size of the Desert basin is usually given as about 140,000 square miles, this figure might well be somewhat too small.

In the present state of knowledge it is, therefore, impossible to indicate thickness and distribution of facies for the entire basin. Certain possibilities only can be suggested.

It is fairly certain that the sedimentary sequence of the basin is made up of rocks of Devonian and Permian age; to these, Jurassic rocks may possibly be added. The succession in the northern part of the basin is as follows.

		Feet
Permian	Erskine series. Conglomerates, sandstones, shales	350
	Upper Ferruginous series. Clays, grits, sandstones	1,400
	Nooncanbah series. Shales, limestones	1,200
	Lower Ferruginous series. Grits, sandstones, shales	2,200
	Nura Nura limestone	20
	Various sandstones and boulder beds. Grant Range series, Kungangie series, Willanyie series. Up to	2,300
Upper Devonian	Reef limestones, passing southeastward into conglomerate sandstones, shales of decreasing thickness	Maximum 5,000±
Middle Devonian	Reef limestones and brachiopod limestones	

The maximum thickness of Paleozoic sediments in this part of the basin may thus be as much as 12,500 feet.

Whether or not this thickness is maintained basinward is at present entirely a matter of speculation. From observations along the Canning Stock Route in the southeastern part of the basin it seems that sandstones in a more or less horizontal position underlie much of the interior of the basin; and since the beds in the northeastern part of the basin dip southwest, that is basinward, it may be expected that the sandstones of the interior are rather high in the sequence. This is also borne out by aerial observations in the northeast corner of the basin.[81] Also in the northwestern part of the basin Clapp found evidence of a thick sandstone series along the edge of the interior plateau of the basin. It seems that these sandstones must correspond with the higher parts of the Permian series as known in the vicinity of the Fitzroy River (Liveringa and Erskine series, and perhaps higher); and there is thus every indication of the existence of a considerable thickness of Paleozoic sediments in the interior of the basin.

What happens to the Devonian in the interior of the basin is at present entirely unknown, though there are indications that the limestone facies, much in evidence along the northeastern margin of the basin, might not continue far into the interior. An old artesian bore 67 miles east of Derby and only about 8 miles from the limestone scarp of the Napier Range has the following interesting log (greatly condensed from the original).

[81] H. G. Woolnough, *Report of Aerial Survey Operations in Australia during 1932*, p. 49. By Authority: Canberra (1933).

	Depth in Feet
Sandstones with very little shale; conglomerates near the base	3–1,059
Fossiliferous limestone	1,059–1,170
Very hard to sandy limestone	1,170–2,131
Sandstone with very little shale	2,131–3,012

The bore first went through 1,059 feet of basal Permian sandstones. Below this level the Devonian was no doubt entered and the "fossiliferous limestone," here about 110 feet thick, must be the *Productella* limestone. At 1,170 feet the bore entered the massive reef limestones of the Upper Devonian and continued in them for 961 feet. The rest of the section (981 feet) is in sandstone which is not known from outcrops in the Napier Range. It is very probably the sandy facies of the Middle Devonian which appears here in the bore.

Nothing more is known about the Devonian nearer the center of the basin. Permian fossils have been found at well No. 27 on the Canning Stock Route, only a few miles from the southwestern margin of the basin. It is possible that the Devonian is here buried (perhaps downfaulted along the edge of the basin) but it is equally possible that no Devonian is present in this part of the Desert basin.

Finally, Jurassic beds appear in the stratigraphical column of the northwestern part of the basin, toward the coast, where the basin probably deepens appreciably. Below Broome there are at least 500 feet of marine Jurassic shales and sandstones (from approximately 900 to 1,400 feet). The beds between the surface and 900 feet are probably at least partly Jurassic (lacustrine); some of them may be Tertiary. Below 1,400 feet there is an increasingly sandy section down to 1,775 feet which is as deep as the deepest bore has penetrated the sequence. Thus, we find post-Paleozoic rocks down to at least 1,400 feet, possibly still deeper. Farther inland, the marine Jurassic beds rise closer to the surface; 20 miles south of Derby they occur at not more than 300 to 400 feet below sea-level, although their thickness here is not known. At Derby there seems to be a subsurface section of about 300 feet of lacustrine Jurassic sandstones, underlain by mostly soft sedimentary rocks, apparently mostly shale and sandstone which have been traversed by the Derby Town bore to a depth of 2,371 feet. The upper part of this section must be Jurassic, although no fossils have been recovered. Where the Permian begins is at present impossible to say. The writer has examined fragments of bore cores from a depth of 1,860 feet which contain specimens of a large species of *Cleiothyridina* which is characteristic of the lower part of the *Linoproductus* stage of the Wandagee series of the North-West basin, though its stratigraphical horizon in the Fitzroy Permian sequence is not known. From general considerations of the correlation of the two basins it should be expected that this species occurs somewhere near the middle of the Upper Ferruginous series, that is at least 1,000 feet below the top of the Permian, so that the thickness of the Jurassic in the Derby Town bore might thus be between 800 and 900 feet.

If the Paleozoic retains its thickness in the direction of the coastal regions a thickness of sediments in excess of 13,000 feet might be found there.

(c) *North-West basin.*[82]—The sediments of the area known under this name do not shape themselves into a true basin. It would perhaps be more correct to call it a "half-basin" which extends for more than 400 miles from the vicinity of the Murchison River in the south northward as far as Exmouth Gulf and Northwest Cape and may continue still farther north as a kind of coastal basin. Structurally, the large, but shallow (less than 10 fathoms) embayment of Shark Bay and its southern "appendices," Denham Sound, Freycinet Estuary, and Hamelin Pool, must be included in the North-West basin. It is in this latitude that the basin reaches its greatest width of about 200 miles. The total area underlain by sedimentary rocks is approximately 40,000 square miles. All along its eastern side it is bounded by pre-Cambrian rocks of various ages. It seems that in general conditions of normal stratigraphical overlap prevail along this boundary, although it has not been studied in many places.

The sediments have a westerly dip, though this is only true in a most general way. Actually, the strata are undulating and faulted in many places, but structural details are generally not yet well understood. It is true, however, that from east to west higher parts of the stratigraphical sequence are gradually encountered, the thickness of the section increases, and the greatest thicknesses can be expected generally near the coast, though not necessarily along the coast line itself.

The sedimentary column of the North-West basin is composed of rocks of Permian, Jurassic, Cretaceous, and Tertiary age, and present information seems to indicate that the thickness of the sediments increases from the south toward the north at least as far as 24° S. Lat. Beyond that line only the higher parts of the section have been studied.

From disconnected sections in the northern part of the basin between 22° and 24° S. Lat., the following sequence may be compiled.

The thickness of the Permian seems to decrease southward and at about Lat. 25°, along the Gascoyne River, it does not seem to be more than 6,140 feet. The Cretaceous, however, retains its thickness. The Commonwealth paleontologist, Miss Irene Crespin, has kindly informed the writer that in the Pelican Hill bore at Carnarvon she recognizes, from the study of microfossils, Upper Cretaceous, mostly chalk, from 170 to 1,105 feet below the surface, and Lower Cretaceous mudstones, glauconitic sandstones, and limestones down to 2,000 feet.

[82] Many artesian bores have been sunk in the North-West basin, but most of them are percussion bores and samples are available from only a few of these. With nothing but drillers' logs to go on, subsurface correlation is rendered very difficult as many previous attempts show. For example, as long as it was believed that the Wandagee series was predominantly shaly and formed the top of the Permian sequence, it was usual to "recognize" it in bores just below the Lower Cretaceous, whereas it now appears that the uppermost 1,000 feet of the Wandagee are entirely arenaceous and that at least another 700 feet of sandstones ("Wandagee Hill series") are found on top of them. It is at present difficult to place those beds that used to be correlated with the Wandagee series "old style" but they are probably still in the Cretaceous. Similarly, in the southern part of the basin, in the vicinity of Hamelin Pool, it has been customary to regard as Permian the first non-glauconitic sandstone below the Cretaceous greensands and glauconitic clays, at depths of a few hundred feet. The discovery however, of at least 600 feet of quartz sandstones in the lower part of the Cretaceous section on the Murchison River may necessitate a revision of the principles of bore correlation in that area.

			Feet
Tertiary		Foraminiferal and coral limestones	700
Upper Cretaceous		Bryozoan limestones, greensands, marls, and chalk	1,070
Lower Cretaceous		Siltstones, cherts, and glauconitic sands and clays	1,100
Jurassic		Quartzose sandstones	25
Permian	Wandagee series and higher	Sandstones with increasing intercalations of shale in lower half	3,050
	Cundlego series	Interbedded sandstones and shales	1,000
	Bulgadoo series	Shales with few sandstone beds	2,200
		Missing link in section	
	Wooramel and Callytharra series	Sandstones and calcareous shales and limestones	850
	Lyons series	Sandstones, conglomerates and boulder beds—possibly up to	2,400
		Total	12,395

There are no samples available from 2,000 to 2,474 feet, but from the official log of the bore the writer would be inclined to conclude that the top of the Permian is here at 2,307 feet. This would agree with figures to be deduced from the log of the Boolathana Bore No. 4, 12 miles north of Carnarvon, where the top of the Permian seems to lie 2,290 feet below the surface.

It may thus be expected that in this general vicinity the total thickness of the sediments of the North-West basin is perhaps not in excess of 8,500 feet.

South of the Gascoyne River the basin widens considerably but much of its width is covered either by the shallow waters of Shark Bay or by Recent surficial deposits so that it is very difficult to gain an opinion of its structure. Along the Wooramel River (about 25° 40′ S. Lat.), the Permian might be no more than 2,800 feet thick. Also it has become more arenaceous, shales apparently being subordinate in this section. No reliable data are available for any of the younger beds in this latitude. At Gladstone, near the mouth of the Wooramel, 540 feet of shales and clays were found in a bore, but apparently the bottom of the Cretaceous was not reached here. Forty miles west, on Peron Peninsula, a bore penetrated 1,750 feet of soft rock, mostly clay and shale (possibly including chalk) and from knowledge of the Cretaceous stratigraphy farther south along the Murchison River, it may be concluded that this bore stopped at least 500 feet short of the bottom of the Cretaceous series. With a possible 2,800 feet of Permian rocks underneath, it seems that even in this part of the basin a minimum thickness of sediments of not less than 5,000 feet may be expected.

South of about 26° S. Lat., the contents of the basin are almost entirely unknown, with the exception of 700 feet of Cretaceous sandstones, shales, and chalk along the lower course of the Murchison River.

TECTONIC CLASSIFICATION OF MAJOR BASINS

In this discussion we may perhaps neglect the recently discovered "Burt Range basin," because too little is known about it at present.

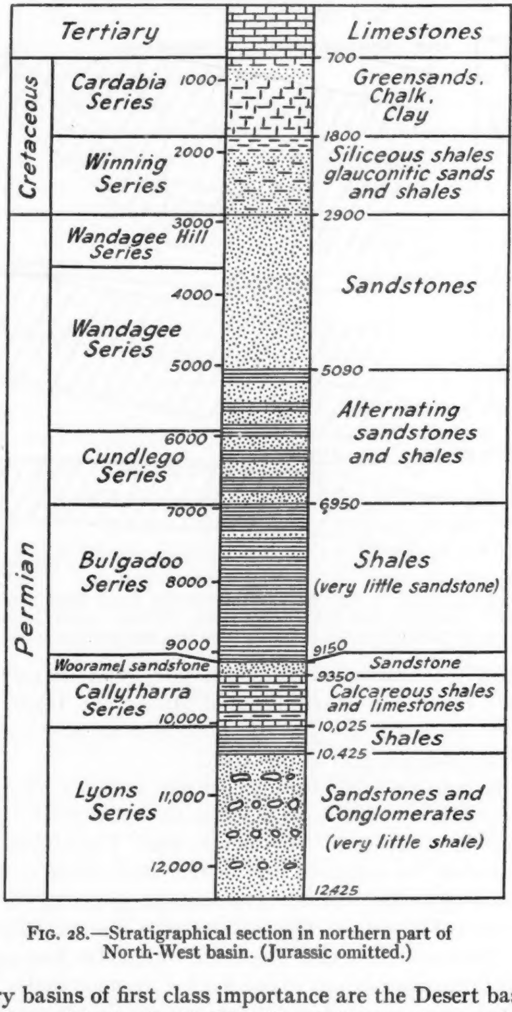

FIG. 28.—Stratigraphical section in northern part of North-West basin. (Jurassic omitted.)

Sedimentary basins of first class importance are the Desert basin, the North-West basin, and possibly the South-West Coastal basin. As regards the latter it is true that many stratigraphical facts are available but its structure is so little known that no clear picture of it can be given and its classification can not be attempted.

The Desert basin and the North-West basin are not exactly comparable. They differ somewhat in size, shape, structure, and in the age of their sediments, and it is well first to concentrate on certain aspects of their sedimentational history.

The Desert basin of 140,000 square miles seems to be more truly basin-shaped, with upturned beds probably around three of its four sides, but deepening

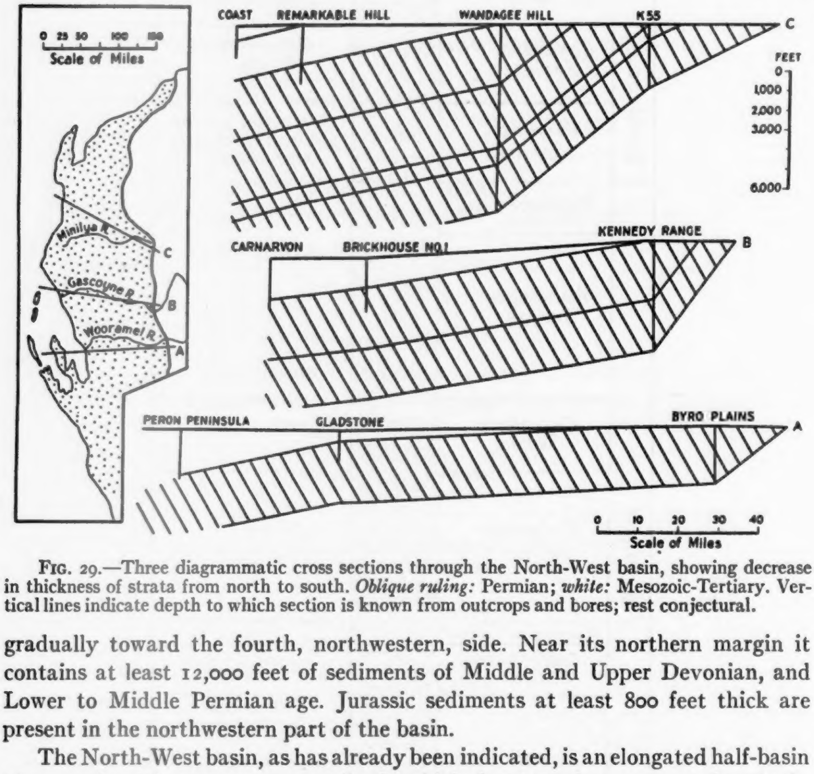

FIG. 29.—Three diagrammatic cross sections through the North-West basin, showing decrease in thickness of strata from north to south. *Oblique ruling:* Permian; *white:* Mesozoic-Tertiary. Vertical lines indicate depth to which section is known from outcrops and bores; rest conjectural.

gradually toward the fourth, northwestern, side. Near its northern margin it contains at least 12,000 feet of sediments of Middle and Upper Devonian, and Lower to Middle Permian age. Jurassic sediments at least 800 feet thick are present in the northwestern part of the basin.

The North-West basin, as has already been indicated, is an elongated half-basin of approximately 40,000 square miles in which the strata have a general westerly dip toward the sea, or rather the continental shelf. The maximum thickness of sediments is found in the northern part of the basin where it may well exceed 13,000 feet. Strata of Lower to Middle Permian age, probably very little Jurassic, and a fair thickness of Lower and Upper Cretaceous, Eocene, Oligocene, Miocene, and probably Pliocene are present. The most remarkable feature of this part of the basin is the thick series (up to 10,000 feet) of Permian shales and sandstones, the bulk of which was deposited in Artinskian time. In the southern part of the basin the thickness of the sedimentary filling decreases to 5,000 feet or perhaps even less.

Areas in which sediments have accumulated in such thicknesses are usually called "geosynclines" or "geosynclinal basins." This conception was first applied to the Desert basin by Forman[83] and extended to the North-West basin by the present writer,[84] who then regarded the two basins as parts of one structural unit, the "Westralia Geosyncline," which, it was suggested, may have formed a southern continuation of the Timor-East Celebes geosyncline of the East Indies, although the troughs showed marked differences in their depositional and orogenetic history.

There is no need in this place to enter into a discussion of fundamental concepts of geotectonics. Not every geologist would class the Western Australian basins as geosynclines. For example, their general features agree well with Tercier's "paralic basins"[85] of the continental shelves. Tercier describes such basins as intracontinental or pericontinental and their sediments as generally thick, in many places several thousand meters, predominantly terrigenous, partly marine, partly estuarine and continental. The marine facies is exclusively neritic, characterized by a predominance of detrital rocks, organogenic rocks being subordinate. They indicate considerable, mostly continuous subsidence. Such series are commonly found marginal to great mountain ranges, for example, the molasse. Other examples are the Neogene basins of Sumatra, Java, and Borneo; the Gulf Coast basin of North America (Gulf Coast geosyncline of Russell and others); the coal basins of western Europe and eastern North America; the Old Red deposits of Europe, Spitsbergen, and Greenland.

Tercier's paralic basins are at least partly identical with Umbgrove's "idiogeosynclines" or "basin geosynclines."[86] This term he coined for the great oil-producing basins of Tertiary sediments on Sumatra, Java, and Borneo which were included by Tercier in his paralic basins. Thicknesses here are up to 20,000 feet, locally even more, and much of the sediments were deposited during the Neogene alone, that is, probably in 20 million years or less.

In Western Australia some Permian sequences have accumulated at the rate of 10,000 feet in 7 to 10 million years. In the East Indian basins sediments did not collect more rapidly.

This interpretation of the North-West and Desert basins of Western Australia is an alternative to the idea of a Westralian geosyncline as set forth in 1939.

Obviously, these considerations are of more than theoretical interest, because Tercier's paralic basins, or Umbgrove's idiogeosynclines, constitute a structural province which is known to contain many important oil fields.

[83] F. G. Forman, "Notes on the Geology and Petroleum Prospects of the Desert Basin of W. A.," *Geol. Survey Western Australia, Ann. Progr. Rept. 1929*, p. 21. Perth (1930).

[84] C. Teichert, "The Mesozoic Transgressions in Western Australia," *Australian Jour. Sci.*, Vol. 2 (1939), pp. 84–86.

[85] J. Tercier, "Dépôts marins actuels et séries géologiques," *Ecl. Geol. Helv.*, Vol. 32, No. 1 (1939), pp. 47–100.

[86] J. H. F. Umbgrove, "Verschillende Typen van Tertiaire Geosynclinalen in den Indischen Archipel," *Leidsche Geol. Mededeel.*, Vol. 6, No. 1 (1933), p. 36.

OIL POSSIBILITIES

The practical significance of many of the stratigraphical facts discussed in this paper is self-evident. In the following paragraphs a few additional points are emphasized, mainly structural, which have been inadequately treated in the preceding chapters.

The presence in Western Australia of large areas of sedimentary rocks attracted the attention of the oil industry long before details of the sections were known, but early investigations were commonly superficial and most later surveys were either of the broad reconnaissance type or they concerned themselves with detailed studies of only small parts of the great basins.

SOUTH-WEST COASTAL BASIN

Little is known about the structure of the South-West Coastal basin. The pre-Cambrian escarpment, known as the "Darling Range" which borders it along much of its east side, is very pronounced along the edge of the Coastal Plain south of Perth and for at least 50 miles north of Perth. Farther north it becomes more indistinct. It has been assumed by many that the Darling scarp is a fault, but there is no direct evidence for this assumption and recent investigations by Prider[87] seem to make the assumption of a monoclinal flexure at least plausible; also it should be remembered that monoclinal coasts adjacent to ancient shields are known at Natal, Mozambique, Greenland, and elsewhere.[88]

All the deep bores put down in search of artesian water are situated near the outer edge of the Coastal Plain, with the exception of the Moora bore, 100 miles north of Perth, which is only $2\frac{1}{2}$ miles from the edge of the pre-Cambrian. If this bore, as seems likely, penetrated as far as the Permian beds, it may be assumed that perhaps there are not more than about 4,000 feet of sediments below the bore site. A slope of the pre-Cambrian surface of not more than 16° would be sufficient to bring it down to this depth and the evidence for the existence of a fault along the edge of the Coastal Plain near Moora as suggested by Forman, is therefore quite inconclusive.

Although study of the surface geology is made difficult by extensive covering of Pleistocene and Recent deposits in the Coastal Plain, Forman located an anticlinal structure in presumably Jurassic sandstones at Walyering Peak, west of Moore.[89] It is usual to assume a more or less general westerly dip of the strata, but there is not much evidence to support such a simple view and conditions

[87] R. T. Prider, 'The Contact between the Granitic Rocks and the Cardup Series at Armadale," *Jour. Roy. Soc. Western Australia*, Vol. 27 (1940–1941), pp. 27–55. 1941.

[88] Interesting samples from various parts of the world will be found in the following papers:
H. Cloos, "Hebung-Spaltung-Vulkanismus," *Geol. Rundsch.*, Vol. 30, Zwischenheft 4A (1939), pp. 503–06.
J. Bourcart, "La marge continentale," *Bull. Soc. Geol. France* (5), Vol. 8 (1938), pp. 467–71.
L. C. King, "Monoclinal Coast in Natal, South Africa," *Jour. Geomorph.*, Vol. 3 (1940), pp. 144–53.

[89] F. G. Forman, "Geology and Petroleum Prospects of Part of O.P.A. 253H. near Dandarragan," *Geol. Survey Western Australia, Ann. Progr. Rept. 1934* (1935), pp. 7–11.

might well be more complicated as suggested by the geological profile west of Moora and by the difficulties experienced in the correlation of the logs of artesian bores at Perth.

The question of the nature of the Darling scarp is of obvious significance for the interpretation of the entire coastal basin. If the scarp owes its origin to a monoclinal flexure, this may well be of great age and indicate the position of, or at least run parallel with, former coast lines of the Mesozoic. The conditions may then be present for the existence of updip wedge-belts of high porosity which have not hitherto been suspected.

NORTH-WEST BASIN

In 1925 a well known oil geologist traversed the North-West basin and condemned it, lock, stock, and barrel, as the most unpromising prospect he had ever had the misfortune to see, his chief reason being that "only a few feet of shale has actually been seen or authentically reported in the basin." Ten year's later after Raggatt's survey for Oil Search Limited,[90] the known thickness of shales in the Permian alone had increased to 2,500 feet to which another 1,000 feet or so of Cretaceous shales were added. In subsequent years the writer has seen at least 4,000 feet of shale in a narrowly restricted Permian area, and present indications are that the combined thicknesses of all Permian and Cretaceous shales in the northern part of the basin must be nearly 6,000 feet.

From the point of view of potential source rocks, therefore, the position is satisfactory and the question of porosity and cover seems to find an equally positive answer. There is no scarcity of pervious sandstone, either interbedded with the Permian shales of the Cundlego and lower Wandagee series, or else topping the Permian sequence. More than adequate cover is provided by the impervious clays and marls of the Cretaceous.

These observations have reference to the northern part of the basin only. A number of additional factors entering into the problem have been analyzed by Condit[91] and it may suffice here to refer to his paper.

The North-West basin is a sufficiently unexplored field in which the search for structures might pay dividends, but much detailed mapping and geophysical prospecting will be necessary. Since the writer first reported on the existence of large-scale faulting in one part of the basin,[92] faulting has been found to be even more intense. Because of the almost perfect planation of much of the surface of the basin, such faults are ordinarily very difficult to detect on the ground and detailed paleontological zoning work was necessary to recognize them in the

[90] D. D. Condit, H. G. Raggatt, and E. A. Rudd, "Geology of Northwest Basin, Western Australia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 8 (August, 1936) pp. 1028–70.

[91] D. D. Condit, "Oil Possibilities in North-West District, Western Australia," *Econ. Geology*, Vol. 30 (1935), pp. 860–78.

[92] C. Teichert, "Recent Research Work in the Permian of Western Australia," *Australian Jour. Sci.*, Vol. 2, No. 1 (1939), pp. 5–7.

field. Aerial reconnaissanse will be of considerable value in future work, because many structure patterns in flat country are easily visible from the air.

Anticlines and domes are present in various parts of the basin. Best known is perhaps the Cardabia Range which is cut out of the western limb of a broad anticline of Cretaceous rocks. Toward the south this anticline probably splits into two or three minor and shallower anticlines and the Cretaceous is covered by Tertiary limestones. Other anticlines which have been known for some time are the Cape Range anticline and the Giralia anticline.

In the Permian belt an anticlinal structure was discovered in 1941 in the Bulgadoo shales, south of the Minilya River, and a small dome in strata still lower in the sestion is known from the vicinity of Dairy Creek, south of the Gascoyne River. Both these structures are too low in the sequence to be of any interest to the oil geologist and the same will probably apply to most other structures in the Permian belt, where considerable thicknesses of strata have been removed by erosion and the highest Permian beds are found only along its western margin.

The young age of these deformations is evident. There is at present no clear evidence for more than one tectonic phase and this is not older than Pliocene, since Miocene limestone, possibly even Pliocene, have been folded. The youthfulness of the structures is a factor that must be regarded as favorable to the accumulation and preservation of oil.

Permian oil, if present, will most probably not be found in the areas of Permian outcrops, but farther west where the Permian is covered by Mesozoic and Tertiary sediments. It is, therefore, necessary first of all to obtain an idea of the probable conditions of the concealed Permian sediments in the coastal areas. It will be necessary to establish the maximum thickness of the shales, their exact place in the stratigraphical column, and their geographical distribution. The directions of changes in porosity must be studied. The question of buried hills and of the nature of the contact between the Permian and the Cretaceous (or Jurassic?) must receive close attention. These and other relevant problems can only be approached on the basis of an integrated picture of the geology of the whole basin. In one section south of the Minilya River the writer has seen indications of lateral change from shale to sandstone in a westerly direction, conjuring up vistas of borderlands or buried islands. This and the over-all westerly dip of the beds suggest possibilities for the presense of porosity belts.

DESERT BASIN

Little need be said about the Desert basin. Six-sevenths of it are unexplored and the stratigraphy of the remaining seventh, the Fitzroy River basin, has been described on some preceding pages. In the Devonian there is a bewildering variety of facies, including Upper Devonian shales near the northeast corner of the basin. The Permian has thousands of feet of sandstone, but intercalated are shales,

particularly in the middle and lower part of the section. The relationships between the Devonian and the Permian have only been incompletely investigated.

From the Fitzroy area Wade[93] has described a number of structures which he regarded as promising. A bore was commenced in the Nerrima Dome in strata of the Nooncanbah series. It had reached a depth of more than 4,000 feet when the war brought about the temporary cessation of boring operations. Earlier bores (Mt. Wynne, Poole Range, Price's Creek) were made after brief reconnaissance surveys only. Their lack of success is not surprising.

The beds in the interior of the basin seem on the whole to have a more or less horizontal attitude, but the true structure of the basin is as yet unknown. Very extensive geological surveys will be necessary before the possibilities of this basin as a whole can be properly assessed.

CONCLUSION

During the past 8 years the writer has spent many months in the field on investigations in all the major and many minor sedimentary areas in the state, with the exception of the inland districts which are still more difficult of access than most of the rest and he has seen at least parts of all major areas from the air. The costs of most of these travels were defrayed by the Commonwealth Research Grant to the University of Western Australia under a research program approved by the Council for Scientific and Industrial Research, but work in the Kimberley Division would not have been possible without facilities having been provided on different occasions by Freney Oil Company Limited, Caltex (Australasia) Oil Development Pty. Ltd., and the Mines Department of Western Australia.

Acknowledgment must be made of a debt of gratitude to earlier as well as more recent investigators of sedimentary rocks in Western Australia: E. T. Hardmann, A. Gibb Maitland, A. Wade, E. de C. Clarke, F. G. Forman, H. G. Raggatt, and others; and to those who pioneered the paleontology of this state: R. Etheridge, Jr., and F. Chapman, who laid the foundations of systematic paleontology in Western Australia. In his own work the writer has been ably and unselfishly assisted by many fellow paleontologists. Among those who in recent years have helped in the task of identifying and describing material from the vast paleontological storehouse of Western Australia are: R. S. Bassler (Bryozoa), Irene Crespin (Foraminifera, and Bryozoa), H. O. Fletcher (Pelecypoda), Dorothy Hill (corals), Joan Crockford (Bryozoa), B. F. Howell (sponges), W. J. Parr (Foraminifera), J. Pia (Algae), K. L. Prendergast (Brachiopoda), L. F. Spath (ammonoids), C. J. Stubblefield (trilobites), A. B. Walkom (plants), F. W. Whitehouse (trilobites).

Special acknowledgment is made to Professor E. de C. Clarke, head of the department of geology of the University of Western Australia, and to F. G.

[93] A. Wade, *The Geology of the West Kimberley District of Western Australia*. Final Report on Concession Held by Freney Oil Company, Perth (1936).

Forman, former Government geologist of Western Australia. Both have proved loyal friends in difficult times and without their confidence and collaboration the writer could have achieved little in Western Australia.

Much, very much, remains to be done. Large areas of the state, which there is every reason to believe are underlain by sedimentary rocks, have never been seen by a geologist and not one of even the minor sedimentary areas may be regarded as well known. The number of undescribed, new species at present in collections in this state is probably not far from one thousand. Among them are many of the commonest Western Australian fossils. Investigations into the distribution of facies and the sedimentary environment of the major basins, and paleontological zoning have only just begun. Future researches of this kind are bound to alter many present conceptions of the stratigraphy of Western Australia. The present paper, therefore, can be no more than a beginning and a challenge—

but, for the rest, we must partly investigate for ourselves, partly learn from other investigators, and if those who study this subject form an opinion contrary to what we have now stated, we must esteem both parties, indeed, but follow the more accurate (Aristotle, Metaphysics).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 1 (JANUARY, 1947), PP. 71-91, 1 MAP.

STRATIGRAPHIC PALEONTOLOGY OF CAMAGÜEY DISTRICT, CUBA[1]

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ABSTRACT

Late Jurassic to Eocene rocks associated with the serpentine of the Camagüey chromite district, Cuba, comprise a southern shallow-water facies, made up chiefly of pyroclastic material, and a northern deeper-water, calcareous facies. Extensive thrusting has superposed the northern facies over the southern sediments and igneous rocks.

The oldest fossiliferous rocks in the district are thin-bedded Upper Jurassic (Portlandian) and Lower Cretaceous (Neocomian) limestones of the northern facies in the Sierra de Camaján, an outlier of the main thrust sheet.

Upper Cretaceous rocks of three epochs are recognized: the La Fé limestones (late Santonian or Campanian) and the Yucatán limestones (late Campanian) belong to the southern facies; the Habana formation (Maestrichtian) represents both the southern facies (shales and gravels, and limestones with *Barrettia*) and the northern facies (limestones of the Sierra de Cubitas and Sierra de Camajan).

A tentative age of latest Cretaceous passing into Paleocene is assigned to thick-bedded, porcellaneous white limestones which contain *Borelis*, Miliolidae, and small Foraminifera.

Fossiliferous marls, limestones, and calcareous shales overlying the Cretaceous beds are correlated with lower Eocene rocks in western Cuba; and limestones, limestone conglomerates, marls, and shales are assigned to the middle Eocene.

Faunal lists are given for each formation and lithologic unit described.

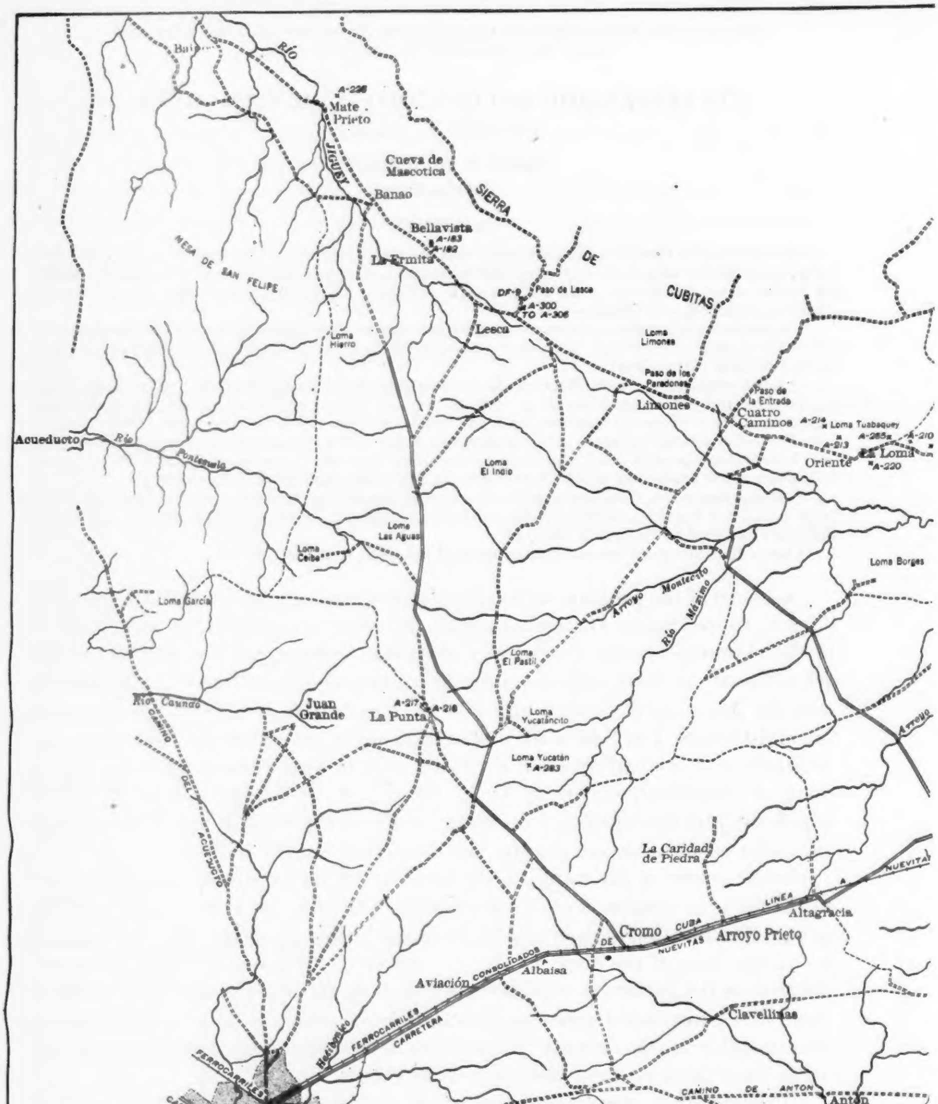
As a part of the program of investigations of strategic minerals, the Geological Survey, United States Department of the Interior, has mapped the areal geology of the chromite-bearing district of Camagüey, Cuba, under the auspices of the Department of State and the Interdepartmental Committee for Cooperation with the American Republics, and with the cooperation of the Foreign Economic Administration. The field work was carried out in several stages, but more continuously and intensively from the latter part of 1943 through the first half of 1944. A preliminary report by D. E. Flint, J. F. de Albear, and P. W. Guild, which will give the significant economic results of the work, is in course of preparation for publication as a chapter in a Geological Survey *Bulletin*.

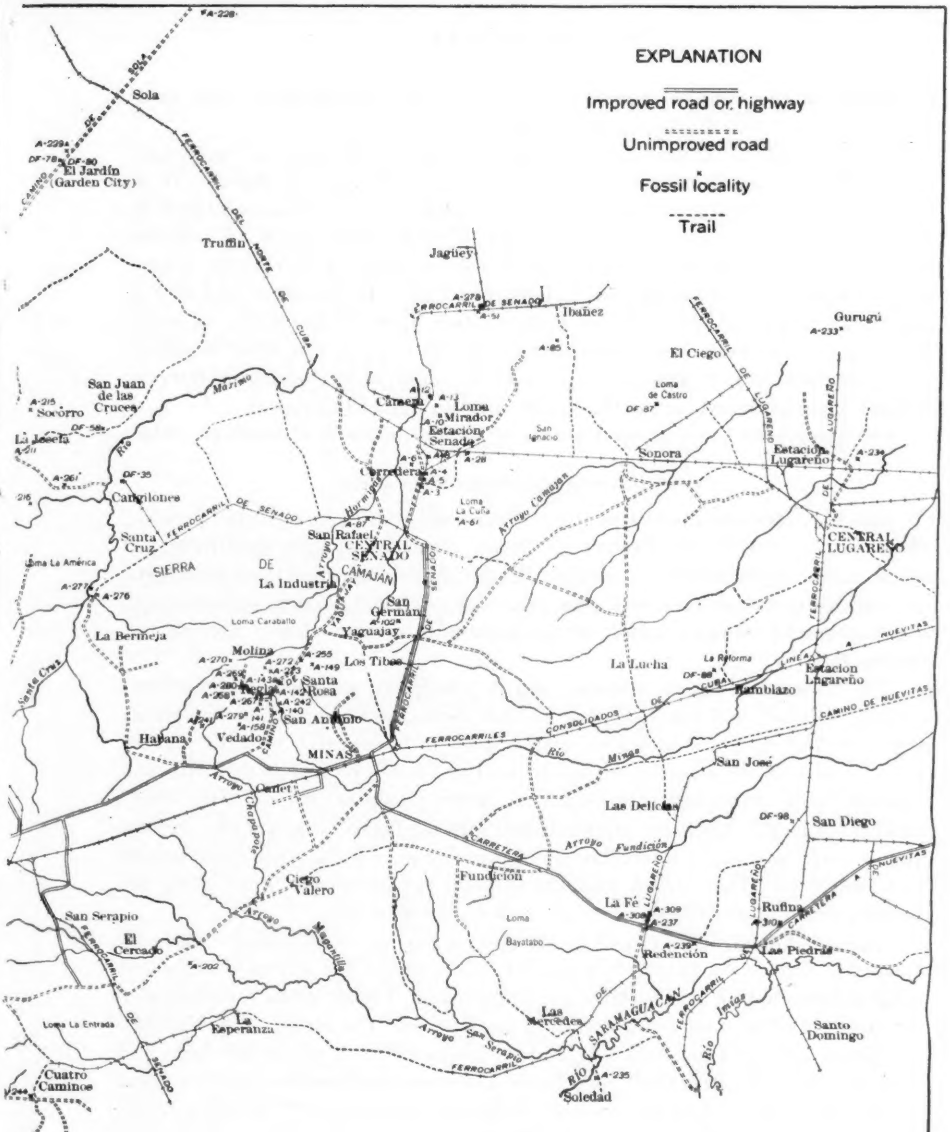
In the course of the mapping, the areas underlain by sedimentary rocks were examined and samples were systematically collected by Flint, Guild, and the writer. The location of each sample discussed in this paper has been indicated on an outline map of the district (Fig. 1). Not all of the samples were fossiliferous; because of the particular conditions of exposure, superficial collecting, derivation from much-weathered zones, or recrystallization, many samples yielded only indeterminable molds. Seventy thin sections have been prepared of samples of hard rocks that could not be studied by other methods.

This report is merely preliminary. It does not present a detailed and systematic study of the species encountered, but faunal lists are given for each formation or for the principal samples, though the material of each sample has not been completely examined. Further, with the field notes and data and the ob-

[1] *Published with the permission of the director of the Geological Survey, United States Department of the Interior. Manuscript received, April 29, 1946.*

[2] Geologist, Geological Survey; member of the Comisión Geológica de Cuba.


Mate Prieto
A-226
Río Jiguey
Cueva de Mascotica
Banao
Sierra de Cubitas
Bellavista
A-183
A-182
La Ermita
Mesa de San Felipe
DF-9
Paso de Lesca
A-300 to A-306
Lesca
Loma Hierro
Loma Limones
Paso de los Paredones
Limones
Paso de la Entrada
Cuatro Caminos
A-214
Loma Tuabaquey
A-213
A-265
A-210
Oriente
La Loma
A-220
Acueducto
Río Pontezuela
Loma El Indio
Loma Las Aguas
Loma Ceiba
Loma Borges
Loma García
Arroyo Montecito
Río Máximo
Loma El Pastil
Río Caunao
Juan Grande
A-217
A-218
La Punta
Loma Yucatancito
Loma Yucatán
A-283
Camino del Acueducto
La Caridad de Piedra
Nuevitas
Línea
Altagracia
Cromo
Cuba
Arroyo Prieto
Ferrocarriles Consolidados de Cuba
Aviación
Albaisa
Carretera
Clavellinas
Ferrocarriles
Carretera
Camino de Antón
Antón
Miradero
El Peñón
DF-126
DF-129
DF-130
Loma El Peñón
A-307
A-243
Miranda
Río Seco
Río Tínima
Consolidados
Central
A-153
PG-18
CAMAGUEY
La Purísima
A-249
A-250
Montejo
Arroyo Hondo
A-294
Camino de Maraguan
Cuba
Santayana
Las Cruces
A-252
San Isidoro



MAP OF

CAMAGUEY DISTRICT, CUBA, SHOWING FOSSIL LOCALITIES

BASED ON MAP COMPILED IN 1943 BY U. S. GEOLOGICAL SURVEY

servations on the samples themselves, lithologic and stratigraphic notes have been prepared, which it is hoped will be useful.

The paleontologic determinations were made during the winter of 1944–1945, in the offices of the Comisión del Mapa Geológico, Ministry of Agriculture of Cuba, at Ciénaga, Habana, thanks to the enthusiasm and continuous interest in geologic studies always shown by the director, Jorge Brödermann. Much help has been obtained by the use of the private library of Pedro J. Bermúdez, micropaleontologist of the Standard Oil Company of Cuba. To the generosity of this company the writer owes also the authorization given to Bermúdez to make determinations of various samples about the middle of 1944. The writer is particularly indebted to J. B. Reeside, Jr., and P. W. Guild, of the Geological Survey, for their comments and for the translation into English of this report.

The observations and determinations by periods follow in chronologic order.

UPPER JURASSIC—LOWER CRETACEOUS

Lithologic character and stratigraphy.—Sediments considered of Upper Jurassic (Portlandian) and Lower Cretaceous (lower Neocomian) ages constitute the oldest marine deposits in the Camagüey district. In this report all these sediments are assigned to a single unit until more precise and detailed geologic, paleontologic and topographic studies permit better knowledge of the relative ages of the various beds.

The material is rather uniform, and is principally well bedded limestone, strongly lithified, and generally thin-bedded, dense, and compact, of fine grain, yellow to brown, at some places whitish gray to bluish gray or with pinkish tones. The beds are almost everywhere hard and much recrystallized, with fine veins of calcite irregularly distributed. At certain localities, dense cherts, locally pinkish but mostly black, are interstratified with the limestone as are also creamy yellow marls and minor intercalations of greenish gray tuffs, apparently altered and weathered. When struck with the hammer the limestones break along the bedding and almost without exception emit a petroleum odor.

These sediments are exposed in the central part of the so-called "Sierra de Camaján" on the old Fundo de Yaguajay, northwest of the village of Minas, in what appears to be a broadly elliptical domical fold. The structure is complicated by strong folding, faulting, fracturing, and erosion. The strata here described occupy an area 5.5 kilometers long and 1.7 kilometers wide within the dome and form rounded hills, irregularly distributed and separated from the dome by small valleys. Thin slices of limestones and calcareous conglomerates belonging to the Upper Cretaceous (Maestrichtian) have been observed in the valleys cut into the dome, and rocks of this age have been mapped at many spots around its border. The minimum thickness of 1,200 feet is estimated for this Jurassic-Lower Cretaceous unit.

Field evidence indicates that these limestones have been thrust southward at least 6 miles over the surrounding serpentine. A coarse breccia-conglomerate con-

taining fragments of nearly all the known igneous and sedimentary rocks of the district, exposed near Central Senado and elsewhere in the vicinity of the Sierra de Camaján, is believed to have been formed along the sole of this overthrust. Samples A-276 and A-277 are apparently from the breccia zone, as no other near-by outcrops of rocks of this age are known.

There are several occurrences of asphaltic material within the dome, principally in pits and other exploratory excavations on the Fincas Habana and Regla. They have recently been described by Brödermann[3] in a bulletin devoted to the asphalt deposits of Cuba.

TABLE I

UPPER JURASSIC-LOWER CRETACEOUS FAUNA

	Camaján																		*Breccia-Conglomerate of Senado*									
	A-102	A-140	A-141	A-143 b	A-149	A-255	A-241	A-242	A-266	A-267	A-268	A-269	A-272	A-273	A-274	A-276	A-277	A-279	A-3	A-4	A-6	A-8	A-10	A-12	A-13	A-28	A-51	A-61
Dickersonia sabanillensis Imlay			x																									
Durangites vulgaris Burckhardt			x																									
Parodontoceras antilleanum Imlay								x	x		x																	
Parodontoceras sp.			x																									
Leptoceras? sp.																							x					
Lamellaptychus seranonis (Coquand)				x							x												?					
Lamellaptychus sp.	x				x					x		x						x	x	x	x	x	x	x	x	x	x	x
Ammonites sp.					x		x	x	x				x	x	x			x	x	x	x	x			x	x		
Radiolarians	x	x				x										x	x											

Fauna.—The fauna is principally macroscopic, and contains many aptychi and some ammonites, all generally very poorly preserved and recrystallized. The microfauna is practically restricted to abundant Radiolaria, especially of the spheroidal and discoidal types, but with few distinct species.

From some of the traverses made it is suspected that a separation of the unit into two stratigraphic divisions may be effected, one with ammonites of relatively large size and few aptychi, the other with a predominance of aptychi associated with much smaller, worn ammonites, most of which are poorly preserved. However, the lack of a good section, well exposed and uncomplicated by folding or faulting, prevented certain and satisfactory conclusions from being reached.

Good specimens of macrofossils were not obtained, but several authors[4] have already contributed to the determination of part of the fauna of this zone. The localities visited are cited, however, in order that they may be of use to future students, and the suggestion is offered that careful search be made on the Fincas Vedado, Habana, Santo Domingo, Magdalena, San Antonio, Nueva María, Santa Rosa, and especially the Finca Regla in the central part of the dome and the Finca San Juan Bautista, near the Callejón (secondary road) de Molina.

[3] J. Brödermann, F. Villoch, and A. Andreu, "Yacimientos asfaltíferos de Cuba," *Direc. de Montes, Minas y Aguas, Boletín de Minas Núm. 19* (1945), pp. 128, 129.

[4] H. J. MacGillavry, "Geology of the Province of Camagüey, Cuba, with Revisional Studies in Rudist Paleontology," *Geog. Geol. Mededeel. Physiog. Geol. Reeks 14* (1937). 169 pp., 3 pls.

R. W. Imlay, "Late Jurassic Fossils from Cuba and Their Economic Significance," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1417–78; 12 pls., 4 figs.

In spite of the dearth of characteristic macrofossils, some samples from these beds, or from beds identical with them in lithologic character, have been sectioned and have shown Radiolaria. These samples are indicated in Table I, as are also those limestone samples which, although collected from exposures of the breccia conglomerate near Central Senado, show by their fossils that they come from the strata under discussion.

It should be noted that, according to MacGillavry,[5] E. Jaworski of Bonn, Germany, identified two species, *Neocomites* cf. *N. neocomiensis* D'Orbigny and *Oppelia* cf. *O. nisoides* Savarin, from his locality L-656, apparently near the boundary between the Fincas Habana and Vedado in the Sierra de Camaján, suggesting that part of the area under consideration belongs to the lower Neocomian. However, this evidence is conflicting, as the species *nisoides* is now placed in the genus *Aconeceras* and is of Aptian age.

UPPER CRETACEOUS

In the Camagüey district, as in other parts of Cuba, the Cretaceous is characterized by a great amount of volcanic rocks. Some tuffs in the area under discussion may be contemporaneous with the Jurassic-Lower Cretaceous clastics, but most were probably deposited during Upper Cretaceous time. The fossiliferous samples belonging to the Upper Cretaceous may be grouped in three principal stratigraphic divisions: (1) La Fé limestones, probably late Santonian or Campanian in age; (2) Yucatán limestones, late Campanian in age; and (3) Habana formation, clearly Maestrichtian in age.

The La Fé limestones comprise a group which includes: (1) gray to black, recrystallized, hard limestones in beds 0.5 to 5 inches thick, interstratified with lenticular beds of yellowish and gray marl; (2) greenish yellow, thin-bedded, friable, fine-grained tuffaceous clays, with impure, hard, gray limestones; and (3) compressed, fine-grained, sandy clay strata. Thin, black, cherty beds are associated with the limestones. Dips, due to moderate folding and minor faulting, are gentle, averaging 20° and ranging up to 35°.

The best exposures of these beds were seen on the Finca La Fé, less than a kilometer from the village of Redención; one is in the cut near the crossing of the railroad of Central Lugareño and the Nuevitas highway (samples A-237, A-308, A-309), material from which is used for ballast on the railroad lines of the Central, and the other is in the cut of the Nuevitas highway at the main gate of the Finca La Fé, 1.3 kilometers west of the first cut. Although no paleontological proof is available, this unit probably includes the hard, gray and black, recrystallized limestones that may be observed at two principal localities rather distant from the Finca La Fé. These localities are: the gentle fold near the dwelling house of the Finca La Reforma, north of Kilometer 45 of the railroad from Nuevitas (sample DF-44-88); and the so-called Loma de Castro, a small limestone hill

[5] H. J. MacGillavry, *op. cit.*

approximately 2 kilometers north of Sonora Station on the Ferrocarril del Norte de Cuba (sample DF-44-87).

Fauna.—The fauna consists of relatively small Foraminifera, in general much recrystallized and broken, Radiolaria, and sponge spicules. Neither macrofossils nor large Foraminifera were seen.

These beds appear to be contemporaneous with part of the Méndez formation of Tampico, Mexico, and with the Taylor formation of Texas. On the basis of the assemblage of the Foraminifera and the presence of abundant and characteristic species of the radiolarian *Baculogypsina?* it is suggested that these beds may correspond with the Papagayos of Mexico (transition between the San Felipe and Méndez formations), but additional good specimens and further study are necessary for an exact correlation. The notable absence of orbitoids and camerinas, characteristic species of the Habana formation, favors the suggestion of a pre-Maestrichtian age. These beds are assigned tentatively to an upper Santonian or Campanian age.

From the principal cut were taken three samples, A-237, A-308, and A-309. The first, except for *Globotruncana* sp. and unidentifiable recrystallized Foraminifera, provides only abundant Radiolaria. The material of sample A-309 came from marls and is poorly preserved; small species predominate. Nevertheless, some species also present in sample A-308 were found, as follows.

Haplophragmoides sp.
Clavulina amorpha Cushman
Clavulina trilatera Cushman var. *whitei* Cushman
Gyroidina crassa (D'Orbigny)
Globigerina cretacea D'Orbigny
Globigerina velascoensis Cushman
Baculogypsina? gallowayi White (radiolarian)
Radiolarians, disks, spheres, and crosses

In sample A-308 were observed the following species.

Saccorhiza ramosa (Brady)
Rhizammina indivisa Brady?
Saccammina scruposum (Berthelin)
Kalamopsis sp.
Nodellum velascoensis (Cushman)
Glomospira charoides (Jones and Parker)
Trochamminoides proteus (Karrer) (*Haplophragmoides coronata* (Brady))
Dorothia (*Gaudryina*) *retusa* (Cushman)
Pseudoclavulina amorpha (Cushman)
Clavulina trilatera Cushman var. *whitei*, Cushman
Dorothia bulletta (Carsey)
Rzehakina epigona (Rzehak)
Quinqueloculina sp.
Astacolus velascoensis White
Lenticulina gaultina (Berthelin)
Lenticulina navicula (D'Orbigny)
Cristellaria grata Reuss
Palmula (*Flabellina*) *suturalis* Cushman
Palmula (*Flabenilla*) *rugosa* (D'Orbigny)
Nodosaria concinna Reuss
Nodosaria (*Glandulina*) *manifesta* Reuss
Nodosaria soluta (Reuss)
Chrysalogonium sp.
Vaginulina cf. *V. trilobata* (D'Orbigny)
Vaginulina truncata Reuss
Frondicularia sp.
Lagena apiculata Reuss
Lagena aspera Reuss var. *apiculata White*
Lagena marginata D'Orbigny
Lagena orbignyana (Seguenza)
Polymorphina velascoensis Cushman
Ramulina globulifera Brady
Pleurostomella velascoensis Cushman
Pleurostomella subnodosa Reuss
Ellipsoglandulina velascoensis Cushman
Gyroidina crassa (D'Orbigny)
Gyroidina cf. G. *florealis* White
Gyroidina naranjoensis White
Gyroidina vortex White
Rotalia velascoensis (Cushman)
Globigerina cf. *G. bulloides* D'Orbigny
Globigerina cretacea D'Orbigny (*Globigerina voluta* White)
Globigerina velascoensis Cushman
Globigerina spp.
Globorotalia velascoensis (Cushman)
Globotruncana cf. *G. rosetta* (Carsey)

YUCATÁN LIMESTONES

The Yucatán limestones are hard, recrystallized, creamy yellow to grayish white, and contain a great abundance of rudistids. In weathering the beds disintegrate to produce marly yellow soils, with some superficial red tones. The absence of detritus suggests that these sediments were deposited in more or less tranquil seas, of relatively shallow depth, even with reefs. It is very probable that these limestones rest discordantly on tuffs.

The principal exposures are in Loma Yucatán and Loma Yucatancito, 0.4 mile north, on the Fincas San Luis and Santa Teresa de Yucatán. The same sort of rocks with a similar fauna occur on the lands of the Finca La Punta, 3 kilometers west of Loma Yucatán (samples A-217 and A- 218).

Fauna.—The fauna is characterized principally by the great abundance and variety of species of rudistids as well as by the absence of orbitoids and other Foraminifera found in the highest Cretaceous of Cuba. The consensus is that these limestones are upper Campanian in age.

Some of the macrofossils, especially in Loma Yucatán, attain great size and weight. The principal species are as follows.

Tampsia lopez-trigoi Palmer
Durania curasavica (Martin)
Vaccinites inaequicostatus macgillavryi (Palmer)
Pironea corrali Palmer
Torreites tschoppi Macgillavry
Coralliochama? sp. Palmer
Corals

HABANA FORMATION

This name was employed by R. H. Palmer[6] to designate the beds of the Upper Cretaceous well exposed in the Province of Habana. He subdivided them into four stratigraphic members with well defined lithologic aspects. Later, through similarity of fauna, the same name has been widely applied to the highest beds (Maestrichtian) of the Upper Cretaceous of the whole island of Cuba, although the lithologic composition varies somewhat from place to place.

In the Camagüey district the fauna of the formation coincides rather well with that of the typical Habana formation. Its beds display certain lithologic similarities that, in general, permit grouping into four principal subdivisions: (a) limestones of the Sierra de Cubitas; (b) limestones of the Sierra de Camaján; (c) shales and gravels; (d) limestones with *Barrettia*. The third division corresponds rather well with Palmer's Grandes Cantos beds (Big Boulder Bed member). All of these beds are included in a single faunal unit, such that they correspond practically with one single epoch of sedimentation (Maestrichtian).

Limestones of Sierra de Cubitas.—The limestones that form the bulk of the Sierra de Cubitas are hard, recrystallized, fine-grained, and white to grayish white, displaying in some places thick, well defined beds, although more commonly they are massive and fractured. They are superficially obscured by a

[6] Robert H. Palmer, "The Geology of Habana, Cuba, and Vicinity," *Jour. Geol.*, Vol. 42 (1934), pp. 123-45; 5 figs., 1 pl.

thick mantle of red soil which permits only exposure of the protuberances known as "dog teeth," products of weathering.

The beds dip steeply and are even overturned northward along the front of the mountain, and dip more gently, commonly south, along the top and back slope. As the base of the unit is not known, and it has not been possible to work out the detailed internal structure, its thickness can not be definitely stated, but it is estimated that it may be between 5,000 and 10,000 feet and is probably nearer the lower figure.

These limestones contain few fossils, and those present are widely scattered. Molds of *Biradiolites* predominate, but there are also a few rudistid fragments and, at places, orbitoid foraminifers and some camerinids. Incidentally, *Vaughanina cubensis* Palmer, an index fossil of the Habana formation, was collected from a limestone quarry at Imías, north of the Sierra de Cubitas.

Limestones of Sierra de Camaján.—The northern part of the Sierra de Camaján from Loma La Industria to Loma Borges, is underlain by grayish white limestones very similar lithologically to those in the Sierra de Cubitas, and within and around the flanks of the southern half of the Sierra smaller areas of this limestone are prominently exposed. The hard, recrystallized limestones are considerably fractured and weathered but nevertheless more resistant to erosion than the Jurassic-Lower Cretaceous limestones. They are commonly massive to thick-bedded, but thin, wavy-bedded rocks were found in a few places. The dips are variable, in general being steep toward the south, particularly in the northern part of the Sierra.

Conglomerates and breccias, found principally in the southern part of the Sierra de Camaján, form part of this unit. Sample A-280, from the Finca Regla, is a stratified, medium- to fine-grained limestone with angular fragments of yellowish, thin-bedded limestone, chert, tuff, and serpentine which, although actually a conglomerate, has somewhat the appearance of a breccia. This sample and A-270, a similar conglomeratic limestone from a point about ½ mile north of the main asphalt pit on Finca Regla, contain various orbitoids characteristic of the Habana formation. No fossils have been observed in the limestones of the northern part of the Sierra de Camaján, but at various points near the north contact of the Jurassic-Lower Cretaceous beds Maestrichtian orbitoids and scattered *Biradiolites* fragments have been found.

Shales and gravels.—These beds consist principally of brown shales and fine-grained calcareous sandstone composed chiefly of grains of basic igneous rocks; tuffaceous material, forming beds several meters thick, with intercalations of well cemented calcareous gravels resembling conglomeratic limestones; and beds of very fine-grained limestone, 10 to 40 centimeters thick. At some localities small lenses of yellowish marls may be seen.

The shales and sandstones are very friable and weather to blackish brown clayey soil that closely resembles the soil formed on tuff; the distribution of limestones is shown by loose fragments and slabs of limestone. In the float are very

TABLE II

FAUNA OF HABANA FORMATION

	A-85	A-150	A-153	PG-43-18	DF-44-9	DF-44-98	DF-44-126	A-213	A-214	A-215	A-234	A-239	A-249	A-250	A-252	A-254	A-270	A-278	A-280
Spiroplectammina laevis (Roemer) var. *cretosa* Cushman													x						
Pseudoclavulina amorpha (Cushman)													x						
Marssonella oxycona (Reuss)													x						
Quinqueloculina sp.													x						
Trochammina trinitatensis Cushman and Jarvis													x						
Cristellaria diademata Berthelin													x						
Cristellaria cf. *C. gaultina* Berthelin													x						
Nodosaria spinulosa Montagu													x						
Lagena globosa Montagu													x						
Operculina bermudezi Palmer													x						
?*Camerina cubensis* Palmer													x						
?*Camerina dickersoni* Palmer				?									x	x					
Camerina vermunti Thiadens (*Miscellanea catenula*)													x	x			x		
Gyroidina micheliniana (D'Orbigny)													x						
Lockhartia bermudezi Cole													x						
Eponides umbonata (Reuss)			x										x						
Eponides sp.			x																
Pulvinulinella alata (Marsson)													x						
Globigerina rugosa Plummer													x						
Globotruncana arca (Cushman)													x						
Globotruncana cretacea Cushman			x										x						
Anomalina taylorensis Carsey													x						
Anomalina cf. *A. rubiginosa* Cushman													x						
Anomalina velascoensis Cushman													x						
Orbitoides browni (Ellis)			x										x	x					
Orbitoides palmeri Gravell			x											x					
Orbitoides sp.			x			x					?				x				x
Lepidorbitoides minima H. Douvillé													x						
Lepidorbitoides cubensis (Palmer)				x													x		
Lepidorbitoides palmeri Thiadens			x																
Lepidorbitoides rutteni Thiadens														x					
Lepidorbitoides sp.				x									x						
Pseudorbitoides israelskii Vaughan and Cole	x		x	x			x										x		
Pseudorbitoides trechmanni H. Douvillé	x			x		x								x					
Vaughanina cubensis Palmer	x			x										x	x		x		
Torreina torrei Palmer																		x	
Radiolaria																	x		
Radiolites cf. *R. sanchezi* (Douvillé)					x														
Biradiolites lumbricatus Douvillé					x														
Biradiolites sp.								x		x						x			
Barrettia monilifera (Woodward)												x				x			
Praebarrettia sparcilirata (Whitfield)												x				x			
Acteonella sp.		x																	
Nerinea sp.								x											
Fragments of rustids	x							x	x		x	x			x				

hard and resistant cobbles and rounded boulders of igneous rocks, principally porphyritic.

Upper Cretaceous beds with these lithologic characteristics may be found at various places in the district, but principally on the Fincas Montejo, La Purísima, and Las Cruces east of Camagüey, in the area called "The Arroyo Hondo syncline" by the Dutch geologists,[7] and in part of the cane fields of Central Lugareño north of Las Piedras.

The beds are rather fossiliferous, with a rich fauna of orbitoid Foraminifera, as indicated in Table II.

Limestones with Barrettia.—These limestones perhaps merely correspond with

[7] H. J. MacGillavry, *op. cit.*

special migratory conditions of deposition and may be included in any of the other units described, principally in the shales and gravels. They form massive beds of very hard white recrystallized limestone. The principal characteristic is the abundance of rudistids, the genus *Barrettia* predominating.

Two principal localities have been observed: (1) in the Arroyo Hondo syncline, crossing the road to Maraguán; (2) the vicinity of Las Piedras (sample A-239), crossing the Nuevitas highway.

At various places in Cuba the co-existence of *Barrettia* with other rudistid pelecypods and also with orbitoid Foraminifera characteristic of the Maestrichtian has been demonstrated, which defines the stratigraphic position of the beds completely.

Because these beds are more resistant than the material that surrounds them, they project above the ground and are therefore easy to recognize.

Fauna.—Rudistid pelecypods and large Foraminifera, of shallow-water or coastal-reef habitat, are well represented. The small Foraminifera have been observed only in material coming from exposures of the shales, mixed with small grains of detritus of basic rocks, mica, plagioclase, quartz, chert, and some tuffaceous material.

Various individuals have collected species of rudistids at numerous localities in the Upper Cretaceous of the Province of Camagüey, especially in the region south of the city. In the part to which this report is restricted, they have been observed only at the localities listed in the faunal table.

Sample A-150 comes from a small exposure of calcareous remnants in clayey tuffaceous material, surrounded by serpentine, at the boundary of the Finca El Peñón, near the southern margin of the savannah. This sample is of hard, recrystallized, black limestone, and contains sections of characteristic molds of *Acteonella* and corals. The association, reported at various places in Cuba, of these gastropods with other fossils, such as *Barrettia monilifera* (Woodward), *Titanosarcolites giganteus* (Whitfield), and *Parastroma guitarti* (Palmer), contemporaneous with characteristic orbitoid Foraminifera, indicates that the age may be Maestrichtian.

Sample A-278 is from a block of conglomeratic limestone, white, hard, and recrystallized, near the cut at the Jagüey Junction, at Kilometer 9 of the private railway of the Central Senado. It forms part of the breccia-conglomerate unit of Senado, and *Torreina torrei* Palmer in it shows that the breccia must have been formed later than the time of the orbitoid Foraminifera, that is, post-Maestrichtian.

With regard to the fauna of the Upper Cretaceous, it remains to be said that MacGillavry,[8] in his general revision of the rudistids, reported various species from Fincas Arroyo Hondo, Quesada, Sánchez Agramonte, and Montejo that have not been rediscovered in the traverses on which this paper is based. The

[8] H. J. MacGillavry, *op. cit.*

fincas cited adjoin, or are very near, the Finca La Purísima, east of the city of Camagüey, whence came samples like A-249 and A-250. These species may be found in official or private Cuban collections and are listed as follows.

Bournonia hispida (Douvillé) (*Parabournonia hispida* Douvillé)
Bournonia n. sp. (*Radiolites nicholasi and Bournonia* sp. Douvillé)
Biradiolites cubensis (Douvillé) (*Biradiolites* aff. *B. cancellatus* Whitfield according to Sánchez Roig)
Antillocaprina annulata (Palmer)
?Antillocaprina occidentalis Douvillé
Parastroma sanchezi Douvillé (*Cyclactinia* n. sp. A and B of Douvillé)
Torreites sanchezi (Douvillé) (*Vaccinites sanchezi* Douvillé)
Plagioptychus antillarum (Douvillé) (*Coralliochama antillarum* Douvillé)

UPPER CRETACEOUS-PALEOCENE (?)

Lithologic character and stratigraphy.—The sediments here assigned with doubt to the Upper Cretaceous are not definitely placed in the stratigraphic column of Cuba and are the subject of controversy. Until their fauna and their relations with other formations are better known, they are tentatively designated Upper Cretaceous passing gradually upward into the Paleocene.

The best exposures seen are in the vicinity of the "Cangilones" (Narrows) of the Río Máximo, east of the Sierra de Cubitas. The rock is a white, porcellaneous, thick-bedded to massive, hard limestone. In general, the beds dip gently and at places are horizontal. No definite contact has been found which will permit determination of the true stratigraphic position.

Material derived from these limestones has been found in the breccia-conglomerate of Senado (sample A-87). On the road from Cuatro Caminos to Cangilones, east of Tuabaquey Hill, the serpentine breccia contains angular fragments of limestone with a *Borelis* fauna, species of Miliolidae, and unidentifiable small Foraminifera. In the lower part of Paso de Lesca, in the Sierra de Cubitas, conglomeratic limestones, apparently resting on the typical limestone of the Sierra de Cubitas, contain a fauna identical with that of Cangilones (sample A-302 and A-304).

Fauna.—The fauna is characterized by the association of species of *Borelis*, abundant Miliolidae, and certain small Foraminifera. Thin sections of the present samples were compared with those of known species of *Borelis*, and although some resemblances were noted to a species from the Upper Cretaceous of Mexico and to two species from the Eocene of Jamaica, the determination has not been completely satisfactory. Consequently the fauna reviewed here must be evaluated with reference to its affinities and not be considered as necessarily giving the true stratigraphic position of these limestones. It is cited only to facilitate later studies.

The conglomeratic limestone of sample A-304, from Paso de Lesca, as seen under the microscope, is a consolidated limestone breccia formed of small fragments of several sorts of limestones. Some fragments contain the fauna of *Borelis* and Miliolidae but in other parts of the same rock *Biradiolites* sp. and also foraminifers like *Camerina* cf. *C. vermunti* Thiadens and *Lepidorbitoides* sp. may

be seen, demonstrating the various sources of the material in the limestone breccia.

At Paso de Lesca a thickness of about 50 feet was observed, but much of the section may be faulted out. Nine miles northwest of Banao, outside the map area, a minimum thickness of 700 feet is indicated for these beds.

TABLE III

FAUNA OF UPPER CRETACEOUS-PALEOCENE (?)

	A-87	DF-44-35	DF-44-58	A-216	A-265	A-302	A-304
Borelis cf. *B. cardenasensis* Barker and Grimsdale	x						
Borelis cf. *B. jamaicensis* Vaughan	x		x				
Borelis cf. *B. matleyi* Vaughan	x						
Borelis sp.	x	x	x		x	x	x
Quinqueloculina sp.	x	x	x			x	
Triloculina sp.	x	x					
Miliolidae	x	x	x	x	x	x	x
Polymorphinidae	x		x				
Globigerina sp.		x				x	

LOWER EOCENE

Lithologic character and stratigraphy.—Lower Eocene strata have been found in the Camagüey district only in restricted areas adjacent to the beds of the middle Eocene, although elsewhere in Cuba they are widely distributed. Deposits of this age are composed principally of yellowish-white marls, for the most part easily disintegrated in water, although at some places consolidated and resembling well stratified impure limestone. These beds have been studied particularly as represented by material from Paso de Lesca, where thin beds of marl are interstratified with thin beds of fine-grained, hard limestone. These strata show pronounced dips, having been involved in the Cubitas overthrust.

Although the lithologic aspect of sample A-310 is very different from that here described, its fauna corresponds with that of a part of the lower Eocene. This sample was taken from a water well on the Finca La Rufina, near Tres Esquinas, east of the Las Piedras crossing on the Nuevitas highway. It consists of strata of sandy shale and calcareous sandstone, of brownish color, containing fine grains of igneous and sedimentary rocks. In the washed material may be recognized abundant quartz and mica, fragments of basic and tuffaceous rocks, and also chert and detritus of calcareous recrystallized rock, all bound by a clayey calcareous cement. At the locality cited, as well as in its vicinity, these beds show differing strikes and gentle dips of only 5° to 15°.

The lithologic differences must correspond with differing conditions of deposition. The general texture and faunal characteristics of sample A-310 indicate very tranquil bottoms in almost open seas.

Fauna.—In samples A-182, A-183, A-210, A-229(a), A-235, A-301 and

A-305, the species of Foraminifera are extremely small, much recrystallized, and poorly preserved. The great number of Radiolaria (disks, spheres, bobbins, bells, and crosses) shown by these samples is notable. These Radiolaria are identical with those obtained from typical material from the Toledo stage, the lower part of the Universidad formation of the lower Eocene of Cuba.[9]

Sample A-310 contains also extremely small Foraminifera, in general in good state of preservation, but whose small size increased greatly the difficulty of exact determination. It shows a great abundance of *Globigerina*, *Globorotalia*, Radiolaria, and other pelagic forms. Certain species reported from the Upper Cretaceous of Cuba have been observed, among others, *Globorotalia velascoensis* Cushman, *G. membranacea* (Ehrenberg), and *Clavulina trilatera* Cushman. The last is small and poorly preserved, which contrasts with the good preservation of the rest of the fauna and serves to confirm that these species are not original in the fauna.

Although the major part ot the species listed below are found in all the Eocene of Cuba, in making a comparison of the fauna it is especially notable that there is an association of species like *Loxostoma applinae* (Plummer) from the Midway of Texas, the Aragón formation of Mexico, and the Paleocene Capdevila[10] of Cuba, with *Discorbis havanensis* Cushman and Bermúdez, *Pleurostomella naranjoensis* Cushman, and *Angulogerina naranjoensis* Cushman and Bermúdez, which indicate a lower Eocene horizon for this sample.

Part of the fauna of the sample A-310 is as follows.

Clavulina trilatera Cushman
Dentalina sp.
Nodosaria soluta (Reuss)
Chrysalogonium lanceolum Cushman and Jarvis
Nonion florinense Cole
Nonion micrum Cole
Nonionella sp.
Loxostoma applinae (Plummer)
Pleurostomella alternans Schwager
Pleurostomella naranjoensis Cushman and Bermúdez
Angulogerina naranjoensis Cushman and Bermúdez
Discorbis havanensis Cushman and Bermúdez
Gyroidina soldanii D'Orbigny
Gyroidina cf. *G. orbicularis* (D'Orbigny)
Gyroidina girardana (Reuss)
Eponides principensis Cushman and Bermúdez
Eponides umbonata (Reuss)
Eponides trümpyi Nuttall
Pulvinulinella culter (Parker and Jones) var. *mexicana* Cole
Pulvinulinella velascoensis Cushman
Allomorphina trigona Reuss
Globigerina bulloides D'Orbigny
Globigerina cretacea D'Orbigny
Globigerina triloba (Reuss)
Globigerina velascoensis Cushman
Globorotalia aragonensis Nuttall
Globorotalia crassata Cushman var. *densa* Cushman
Globorotalia membranacea (Ehrenberg)
Globorotalia velascoensis Cushman
Globorotolia wilcoxensis Cushman and Ponton
Anomalina ammonoides (Reuss) var.
Anomalina bilateralis Cushman
Anomalina grosserugosa (Gümbel)
Anomalina dorri Cole
Cibicides cushmani Nuttall
Cibicides havanensis Cushman and Bermúdez
Cibicides lobatulus (D'Orbigny)
Cibicides pseudoungerianus Cushman
Cibicides subspirata Nuttall
Carpenteria proteiformis Goës
Radiolarians

[9] Pedro J. Bermúdez, "Estudio Micropaleontológico de dos Formaciones Eocénicas de las Cercanías de la Habana, Cuba," *Mem. Soc. Cubana Hist. Nat.*, Vol. 11, No. 3 (1937), pp. 151–80.
Jorge Brödermann and Pedro J. Bermúdez, "Contribución al Mapa Geológico de la Provincia de la Habana, Cuba," manuscript in files of Comisión del Mapa Geológico de Cuba.

[10] R. H. Palmer, *op. cit.*

MIDDLE EOCENE

The subdivision of the Eocene of Cuba into three epochs, including middle Eocene, is the subject of great controversy among micropaleontologists who have studied material from the island. Some think that only two units should be recognized, lower Eocene and upper Eocene, including in part of one or the other the beds that other authors assign to the middle Eocene. Nevertheless, comparison with faunas of other countries of the Caribbean and the Gulf of Mexico, especially of the middle Eocene of Florida and that of Mexico, seems to confirm the existence in Cuba of beds corresponding with this unit. More details are supplied in the notes on the fauna.

Lithologic character and stratigraphy.—If indeed the fauna unites the sediments of this division, the variable ecologic conditions tended to produce various lithologic facies.

In the interior part of Paso de Lesca, beds of creamy yellow marl, interstratified with much thinner white limestones and fine-grained, crystalline, hard limestone conglomerates, contain *Dictyoconus* and *Discocyclina* and correspond with the middle Eocene. These extend in various exposures along the south front of the Sierra de Cubitas.

Somewhat north of the Sierra occurs a conglomeratic limestone, very fossiliferous and resembling a coquina because of the great quantity of larger Foraminifera which it contains. It apparently rests on yellowish marls. Even though it is highly fossiliferous, this limestone has not yielded information in proportion to its fauna, for the fossils are fractured, worn, and recrystallized. Some have been identified, however, permitting the inclusion of the beds in the middle Eocene.

At the south edge of the serpentine savannah Loma El Peñón, the westward prolongation of the Sierra de Maraguán is formed principally of dense, hard, white, crystalline limestone. Its beds are highly weathered, which makes the determination of the fossils difficult.

In the region south of Grúa Cuatro Caminos and the prolongation of the Antón road, yellowish friable marls predominate that are covered at some places by hard recrystallized limestones and by a conglomerate containing large Foraminifera and abundant macrofossils—pelecypods, gastropods, echinoderms, all in general poorly preserved, worn, and altered by weathering. These marls cover a wide area and apparently rest on beds of volcanic tuff, although no definite contact was observed.

Sample A-202 comes from a local water well in process of construction in the southern part of the Finca El Cercado, near the Porvenir mine, and represents marine sediments formed of slightly arenaceous, creamy yellow marls and thin light brown arenaceous shales with tuffaceous clays, forming a unit of well defined, thin beds. The dip is very slight toward the south. The sample indicates a rather deep-water facies.

At Paso de Lesca about 50 feet of these beds were measured, but in an undisturbed area, a thickness up to 600 feet may be expected.

Fauna.—The presence of *Discocyclina*, *Lepidocyclina*, and *Operculinoides* is notable in the samples from Camagüey, an association that has been reported in the upper Eocene of the Caribbean region. Nevertheless, the association, in many of the samples, of *Dictyoconus americanus* (Cushman) and related species widely present in the middle Eocene of Cuba permits these beds also to be assigned to the middle Eocene. Cole[11] reports finding in the middle Eocene Lisbon limestone of Florida *Eodictyoconus cubensis* (Cushman and Bermúdez) (*Pseudorbitolina? cubensis* C. and B.), together with *Dictyoconus americanus*, which association is also found in the limestones of Camagüey. Up to this horizon occur also *Amphistegina lopez-trigoi* Palmer and *Gunteria floridana* Cushman and Ponton. The latter is universally considered a good index of the middle Eocene and has been found in Cuba at numerous localities, especially in the samples collected in the vicinity of Peñón, 7 kilometers south of Martí, Matanzas Province, associated with *Dictyoconus* and *Discocyclina*, which agrees with the findings in Camagüey. Some geologists consider that the Peñón beds constitute the lower and middle members of the middle Eocene of Matanzas Province.

Sample DF-44-78, from the road to Sola, in the northern part of the Sierra de Cubitas, shows *Miscellanea* and *Operculinoides* with *Gunteria* and *Eodictyoconus*. Specimens in the thin sections correspond very well with the species described by Vaughan and Cole[12] from Trinidad. These authors establish the range of *Miscellanea* as through the Eocene, with the most typical forms in the lower and middle Eocene.

The fauna, and especially that of sample A-202, coincides rather well with that of the Jabaco formation of the Eocene of Cuba. This formation was formerly correlated with the Tantoyuca formation of Mexico, although only tentatively.[13] Various later studies indicate certain affinities between the fauna of the Jabaco and the Tempoal fauna of Mexico and also indicate that part of the Jabaco may belong to the upper Eocene, whereas other parts may be placed in the middle Eocene.[14]

From all of the considerations set forth, a middle Eocene age may be assigned to the samples shown in Table IV.

As indicated previously, sample A-244 also contains macrofossils, principally

[11] W. Storrs Cole, "Stratigraphic and Paleontologic Studies of Wells in Florida," *Florida Geol. Survey Bull. 20* (1942), pp. 1–89; 16 pls., 3 figs.

[12] T. Wayland Vaughan and W. Storrs Cole, "Preliminary Report on the Cretaceous and Tertiary Larger Foraminifera of Trinidad, British West Indies," *Geol. Soc. America Spec. Paper 30* (1941). 137 pp., 47 pls.

[13] Pedro J. Bermúdez, "Foraminíferos pequeños de las margas Eocénicas de Guanajay, Provincia de Pinar del Río," *Mem. Soc. Cubana Hist. Nat.*, Vol. 11 (1937), pp. 319–46; 1 map; Vol. 12 (1938), pp. 1–26.

[14] W. Storrs Cole and Pedro J. Bermúdez, "New Foraminiferal Genera from the Cuban Middle Eocene," *Bull. Amer. Paleon.*, Vol. 28, No. 113 (1944).

TABLE IV

FAUNA OF MIDDLE EOCENE

	A-211	A-220	DF-44-78	DF-44-80	A-228	A-233	A-243	A-244	DF-44-129	DF-44-130	A-261	A-300	A-303	A-307
Coskinolina cf. *C. cookei* Moberg		x											x	
Dictyoconus americanus (Cushman)	x	x		x			x	x	x	x		x	?	x
Dictyoconus codon Woodring	x													x
Dictyoconus sp.														x
Eodictyoconus cubensis (Cushman and Bermúdez)	x	x	x		x									x
Gunteria floridana Cushman and Ponton			x							x				
Quinqueloculina spp.	x				x									
Miliolidae	x		x						x	x	x	x		x
Camerina macgillavryi Rutten	x													
Camerina petri Rutten							x							
Camerina sp.	x					x								
Miscellanea antillea (Hanzawa)	x	x	x											
Miscellanea tobleri Vaughan and Cole			x											
Miscellanea cf. *M. soldadensis* Vaughan and Cole		x												
Operculinoides floridensis (Heilprin)					x									
Operculinoides ocalanus (Cushman) var. *minor* Barker	x	x	x		x									
Operculinoides trinitatensis (Nuttall)	x				x	x								
Operculinoides spp.	x	x			x	x					x			
Amphistegina cubensis Palmer	x				x			x						x
Amphistegina lopez-trigoi Palmer	x	x						x			x			
Amphistegina sp.					x									
Eoconuloides wellsi Cole and Bermúdez	x	x											x	x
Globigerina spp.	x	x	x											
Globorotalia sp.	x										x			
Anomalina sp.		x												
Eoannularia eocenica Cole and Bermúdez	x													
Discocyclina crassa (Cushman)	x	x						x			x			
Discocyclina cubensis (Cushman)	x	x									x			
Discocyclina cf. *D. grimsdalei* Vaughan and Cole		x												
Discocyclina (*Asterocyclina*) *subtamarellei* (Cushman)		x												
Discocyclina (*Asterocyclina*) *antillea* (Cushman)	x													
Discocyclina sp.	x	x						x			x	x	x	x
Pseudophragmina cf. *P. tobleri* Vaughan and Cole		x												
Pseudophragmina sp.	x													
Lepidocyclina antillea Cushman					x									
Lepidocyclina cf. *L. hubbardi aurarensis* Hodson	x													
Lepidocyclina macdonaldi Cushman					x									
Lepidocyclina pustulosa (H. Douvillé)	x				x									
Lepidocyclina pustulosa tobleri (H. Douvillé)		x												
Lepidocyclina spp.	x	x			x	x							x	

such forms as *Terebratula liothyrina vaughani* Cooke, *Miltha* sp., *Pseudomiltha* sp., and echinoids such as *Hemiaster lopez-trigoi* Palmer.

In the Gurugú quarry, north of Central Lugareño, there was collected loose on the surface the echinoid *Oligopygus sanchezi* Lambert, which was associated with the material of sample A-233, although it probably came from a much higher horizon in the quarry.

Sample A-202, from the Finca El Cercado, is very fossiliferous, with a great abundance of small Foraminifera in good state of preservation that affords the following list.

Textularia marielensis Lalicker and Bermúdez
Clavulinoides marielinus Cushman and Bermúdez
Valvulammina cf. *V. cubensis* Cushman and Bermúdez
Karreriella arenasensis Cushman and Bermúdez
Plectina cubensis Cushman and Bermúdez
Tritaxilina colei Cushman and Siegfus
Tritaxilina cf. *T. pinarensis* Cushman and Bermúdez
Robulus arcuato-striatus (Hantken)
Robulus mexicanus (Cushman)
Robulus pseudovortex Cole
Robulus sp.
Cristellaria propincua Hantken
Lenticulina convergens (Bornemann)
Marginulina subbullata Hantken
Marginulina crepidula (Fichtel and Moll)
Dentalina havanensis Cushman and Bermúdez
Dentalina sp. B? Cushman
Dentalina sp.

Nodosaria soluta (Reuss)
Nodosaria longiscata D'Orbigny
Nodosaria sp.
Chrysalogonium laeve Cushman and Bermúdez
Chrysalogonium tenuicostatum Cushman and Bermúdez
Lagena advena Cushman
Lagena asperoides Galloway and Morrey
Ramulina globulifera Brady
Nonion florinense Cole
Nonion micrum Cole
Operculinoides kugleri Vaughan and Cole
Operculinoides trinitatensis (Nuttall)
Operculinoides spp.
Bulimina arkadelphiana Cushman and Parker var. *midwayensis* Cushman and Parker
Bulimina impedens Parker and Bermúdez
Buliminella grata Parker and Bermúdez var. *spinosa* Parker and Bermúdez
Bolivina marielina Cushman and Bermúdez
Chrysalidinella cubana Cushman and Bermúdez
Uvigerina cf. *U. blanca-costata* Cole
Uvigerina elongata Cole
Uvigerina gardnerae Cushman
Uvigerina rippensis Cole
Uvigerina spinocostata Cushman and Jarvis
Angulogerina macgillavryi Pijpers
Angulogerina naranjoensis Cushman and Bermúdez
Ellipsonodosaria annulifera Cushman and Bermúdez
Ellipsonodosaria cocoaensis (Cushman)
Ellipsonodosaria nuttalli Cushman and Jarvis
Ellipsonodosaria nuttalli Cushman and Jarvis var. *gracillima* Cushman and Jarvis
Ellipsonodosaria verneuilli (D'Orbigny)
Ellipsonodosaria verneuilli (D'Orbigny) var. *paucistriata* (Galloway and Morrey)
Pleurostomella alternans Schwager
Pleurostomella alazanensis Cushman var. *cubensis* Cushman and Bermúdez
Nodosarella acus Cushman and Bermúdez
Nodosarella subnodosa (Guppy)
Ellipsoglandulina principensis Cushman and Bermúdez
Discorbis havanensis Cushman and Bermúdez
Lamarckina cf. *L. atlantica* Cushman
Gyroidina girardana Reuss
Gyroidina soldanii D'Orbigny
Gyroidina cf. *G. soldanii* D'Orbigny var. *octocamerata* Cushman and G. D. Hanna
Eponides lateralis (Terquem)
Eponides lotus (Schwager)
Eponides marielensis Cushman and Bermúdez
Eponides umbonatus (Reuss)
Eponides umbonatus (Reuss) var. *multisepta* Koch
Eponides rutteni Cushman and Bermúdez
Eponides trümpyi Nuttall
Rotalia mexicana Nuttall
Siphonina advena Cushman
Siphonina advena Cushman var. *cubensis* Cushman and Bermúdez
Siphonina nuda Cushman and Bermúdez
Siphonina sp.
Cancris cubensis Cushman and Bermúdez
Pulvinulinella culter (Parker and Jones) var. *mexicana* Cole
Pulvinulinella cancellata Cushman and Bermúdez
Cassidulina cf. *C. labiata* Cushman and Bermúdez
Cassidulina subglobosa Brady
Allomorphina trigona Reuss
Chilostomella ovoidea Reuss
Globigerina cf. *G. bakeri* Cole
Globigerina bulloides D'Orbigny
Globigerina conglobata Brady
Globigerina orbiformis Cole
Globigerina topilensis Cushman
Globigerina spp.
Orbulina universa D'Orbigny
Hantkenina alabamensis Cushman
Hantkenina longispina Cushman
Globotruncana cf. *G. cretacea* Cushman
Globorotalia crassata (Cushman)
Globorotalia crassata (Cushman) var. *densa* (Cushman)
Globorotalia kochi Pijpers
Globorotalia cf. *G. lehneri* Cushman and Jarvis
Globorotalia spinulosa Cushman
Anomalina grosserugosa (Gümbel)
Anomalina bilateralis Cushman
Planulina cf. *alazanensis* Nuttall
Cibicides havanensis Cushman and Bermúdez
Cibicides pseudoungerianus (Cushman)
Cibicides pseudowuellorstorfi Cole
Cibicides sp.
Carpenteria proteiformis Goës
Lepidocyclina pustulosa trinitatis (Douvillé)
Lepidocyclina cf. *L. sanfernandensis* Vaughan and Cole
Lepidocyclina sp.
Discocyclina cf. *D. bullbrooki* Vaughan and Cole
Discocyclina spp.

List of Localities*

Upper Jurassic-Lower Cretaceous

A-102. San Germán, 3 kilometers south of Central Senado and 750 meters west of Senado-Minas highway

A-140. Old road from Yaguajay, north of Progreso mine, near boundary of Fincas Vedado and Regla; 100 meters north of Algarrobo

A-141. Finca Regla, first limestone hill southwest of principal gate of Finca; 3.3 kilometers northwest of town of Minas

* Reference is made to some well known place names which could not be shown on the map for lack of space. They may be found by local inquiry.

A-143-b. Old road from Yaguajay, 625 meters north of principal gate of Finca Regla and 100 meters east of house of Finca Santo Domingo
A-149. Finca Santa Rosa, 1,750 meters northwest of principal cut of Lolita mine and 500 meters east of entry of Finca Nueva María on old road from Yaguajay.
A-241. Finca Habana, 915 meters northeast of main house and 100 meters from Arroyo Chapapote
A-242. Hacienda San Antonio, 335 meters east of old road from Yaguajay and Finca Regla, and 25 meters east of arroyo.
A-255. Junction of Callejón de Molina with old road from Yaguajay, 440 meters north of A-149.
A-266. Finca Regla, 230 meters west of principal gate of Finca, near inner road on north slope of the hill
A-267. Finca Regla, 915 N. 60° W. of principal gate and 625 meters S. 60° E. of asphalt pit
A-268. Finca Regla, 230 meters N. 52° W. of A-267.
A-269. Finca Regla, crest of hill 395 meters N. 20° E. of asphalt pit and 230 meters west of boundary of Finca Santo Domingo
A-272. Finca San Juan Bautista, 230 meters south of Callejón de Molina and 1.2 kilometers northeast of asphalt pit of Finca Regla
A-273. Finca San Juan Bautista, 625 meters southeast of A-272; about 380 meters N. 70° W. of principal building and 305 meters south of Callejón de Molina
A-274. Old road from Yaguajay, or road from La Cubana, 76 meters south of A-143b.
A-276. Road to Santa Cruz, 182 meters east of Río Santa Cruz
A-277. Road to Santa Cruz, 30 meters east of Río Santa Cruz and 182 meters northwest of A-276
A-279. Finca El Vedado, south of Finca Regla, 520 meters south of dwelling-house of Finca Regla

Breccia-conglomerate of Senado

A-3. Finca Corredera, 90 meters east of narrow-gauge railway of Central Senado, 120 meters S. 45° E. of Grúa Corredera, north of Central Senado
A-4. Finca Corredera, 145 meters east of Grúa Corredera on narrow-gauge railway of Central Senado; about 200 meters northeast of A-3.
A-6. Finca Corredera, small hill 182 meters west of narrow-gauge railway of Central Senado, 70 meters west of road to Senado Station on Ferrocarril Norte de Cuba
A-8. Cut in railway of Central Senado, north of Kilometer 2 and 490 meters north of switch near Grúa Corredera; 455 meters south of Senado Station on Ferrocarril Norte de Cuba
A-10. Loma Mirador, 1 kilometer north of Senado Station on Ferrocarril Norte de Cuba, and 570 meters southeast of Grúa Cámara
A-12. Small cut on first curve of railway of Central Senado, north of Grúa Cámara, 255 meters north
A-13. Finca Cámara, 120 meters north of Loma Mirador and 120 meters southeast of Grúa Cámara
A-28. Finca Cortadera (also called Corredera), small cut 70 meters southwest of crossing of the Ferrocarril Norte de Cuba and branch of narrow-gauge railway of Central Senado to San Ignacio
A-51. Cane fields south of cut at Kilometer 9 of narrow-gauge railway of Central Senado; near Jagüey switch
A-61. Loma La Cuña, 260 meters east of landing field of Central Senado

Upper Cretaceous

La Fé limestone

A-237. Finca La Fé, cut in small hill on narrow-gauge railway of Central Lugareño, Redención branch, near crossing of highway from Nuevitas. Sample from extreme south end of cut, 395 meters north of village of Redención
A-308. Finca La Fé, same locality as A-237. Sample taken 9 meters north of A-237 and from beds 3 meters lower stratigraphically
A-309. Finca La Fé, same locality as A-237. Sample taken at extreme north end of cut, 1 meter from ground surface, and 50 meters north of sample A-308

Yucatán limestone

A-217. Finca La Punta, east of Finca Juan Grande and 3 kilometers west of Loma Yucatán
A-218. Finca La Punta, near principal building, very near end of sedimentary rocks, near level plain (savannah)
A-283. Finca San Luis de Yucatán, southern part of Loma Yucatán

Habana formation

(a) Limestones of Sierra de Cubitas

DF-44-9. Paso de Lesca in the Sierra de Cubitas, 500 meters north of road from Lesca to Banao, 395 meters north of serpentine contact
A-213. Finca El Oriente, near base of Loma Tuabaquey, southeast flank of Sierra de Cubitas
A-214. Secondary road near base on south slope of Loma Tuabaquey, in Sierra de Cubitas
A-215. Secondary road west of Finca Socorro, 1,320 meters northeast of house of Amada Gómez, near road from Cuatro Caminos to Caridad de Cangilones; area east of Loma Tuabaquey

A-226. Finca Mate Prieto, west of Banao, 2,840 meters N. 30° W. of Cueva de Mascotica; 425 meters southeast of point where circular boundary of Hato Bainoa cuts Sierra de Cubitas

(b) Limestones of Sierra de Camaján

A-270. Limestone and conglomeratic limestone (south of general zone of chert and altered rocks) 915 meters north of principal asphalt pit of Finca Regla

A-280. Finca Regla, 500 meters east of principal asphalt pit and near curve of principal interior road, where it bends to follow west boundary of Finca Santo Domingo

(c) Shales and gravels

A-85. Finca Ibañez, cane fields 1 kilometer S. 15° E. of Grúa Ibañez on railway of Central Senado, 250 meters west of northwest corner of Lugareño-Senado property line, north of Finca San Ignacio

A-153. Arroyo 400 meters north of main road from Maraguán, east of city of Camagüey, 1,300 meters southwest of Loma El Pato and 100 meters south of contact of serpentine

PG-43-18. Finca in area of Finca El Peñón, in direction of principal road from Maraguán, east of the city of Camagüey; sample collected southwest of sample A-153

DF-44-98. Colonia in cane fields of Central Lugareño, near Las Piedras branch, west of old Union switch and of Finca San Diego. Sample from water well

DF-44-126. Finca El Peñón, 700 meters south of main building of finca, in direction of El Peñón hill

A-249. Finca La Purísima, dry arroyo near boundary of Fincas La Purísima and Montejo, 500 meters south of main road from Maraguán, east of city of Camagüey, and 1,145 meters N. 8° W of main building of Finca Santa Bárbara. Area of Arroyo Hondo

A-250. Finca La Purísima, small undulation of surface near boundary of Fincas La Purísima and Montejo, 305 meters south of sample A-249 and 2.7 kilometers north of Ferrocarril de Cuba. Area of Arroyo Hondo, east of Camagüey

A-252. Finca San Isidro, 425 meters S. 50° E. of Kilometer 580 of Carretera Central, 820 meters S. 45° E. from Santayana crossing of Ferrocarril de Cuba

A-278. Cut at Kilometer 9 of San Luis branch of narrow-gauge railway of Central Senado. Sample comes from conglomeratic limestone of breccia-conglomerate unit of Senado and was collected near Jagüey-Gabriela switch

(d) Barrettia limestones

A-239. Exposure on Nuevitas highway, south of Finca Mayedo, 1,900 meters west of Las Piedras crossing and 1,615 meters east of Redención crossing

A-254. Exposure on main road to Maraguán, between Fincas Montejo and Arroyo Hondo, 3 kilometers east of serpentine contact. Area of Arroyo Hondo, east of Camagüey City

Undifferentiated Upper Cretaceous

A-150. Limestone exposure surrounded by serpentine, 1.5 kilometers southwest of main gate of Finca El Peñón, 1.3 kilometers northwest of extreme western part of Loma El Peñón, 1,600 meters north of Loma El Pato. Area east of Camagüey

A-158. Finca El Vedado, east of Finca Habana, southern part of Sierra de Camaján, 6 meters north of main house and 750 meters north of curve of Nuevitas highway southeast of Progreso mine

A-234. Cane fields of Central Lugareño, 305 meters north of Ferrocarril del Norte de Cuba, 915 meters northeast of crossing of this railway and Chorrera branch of Central Lugareño

Upper Cretaceous-Paleocene (?)

A-87. Finca San Rafael, 1.3 kilometers west of Central Senado, 165 meters south of Santa Cruz-Cangilones branch of railway of Central Senado

DF-44-35. Grúa Cangilones, exposure in front of dwelling-house of Colonia Cangilones of Central Senado, east of Río Máximo

DF-44-58. Secondary road from Cairige or San Juan de las Cruces, midway between house of Martínez on Finca San Juan de las Cruces and house of Enrique Socarrás on Finca La Caridad de Cangilones. Area west of Río Máximo

A-216. Finca of Ramón Ballorgas, 226 meters northwest of crossing of Río Máximo, toward Finca América

A-265. Sample from exposure of brecciated serpentine 180 meters north of road from Cuatro Caminos to Cangilones and 1,250 meters northeast of house of Tomás Usatorres

A-302. Lower part of Paso de Lesca, in Sierra de Cubitas, 38 meters north of sample A-300 and 115 meters north of breccia near overthrust fault

A-304. Lower part of Paso de Lesca, sample 30 meters north of sample A-302

Lower Eocene

A-182. Finca Bellavista, interior road 150 meters north of road from Lesca to Banao and 500 meters south of main front of Sierra de Cubitas

A-183. Finca Bellavista, 11 meters north of sample A-182

A-210. Cistern 1.5 varas (50 inches) deep near house of Amado Gómez, 395 meters north of road

from Cuatro Caminos to Cangilones and 490 meters west of secondary road and San Juan de las Cruces, side opposite Finca La Josefa. Area east of Loma Tuabaquey

A-229a. Water well 90 feet deep in southeast corner of finca of Paul Tate, near secondary road west of main road from Camagüey to Sola. Area north of Sierra de Cubitas

A-235. Road called Camaján, between Fincas Las Mercedes and La Soledad. 90 meters south of Río Saramaguacán and 1,590 meters southeast of Grúa Las Mercedes on railway of Central Lugareño. Area south of Loma Bayatabo

A-301. Lower part of Paso de Lesca in Sierra de Cubitas. Sample 2.5 feet north of sample A-300 and 77 meters north of breccia near overthrust fault

A-305. Lower part of Paso de Lesca. Sample 40 meters south of sample A-300 and 58 meters north of dry gully

A-310. Finca La Rufina, near Tres Esquinas, 1 kilometer northeast of Las Piedras. Water well 9 meters north of Nuevitas highway, near gully

Middle Eocene

A-211. Limestone 8 meters north of house of Amado Gómez, 405 meters north of road from Cuatro Caminos to Cangilones. Area east of Loma Tuabaquey

A-220. Finca La Loma, 455 meters southeast of house of Tomás Usatorres, 500 meters south of road from Cuatro Caminos to Cangilones, and 100 meters north of contact with serpentine. Area southeast of Loma Tuabaquey

DE-44-78. 240 meters from house of F. L. Tucker, on secondary road east of house, on road from Camagüey to Sola. Area north of Sierra de Cubitas

DF-44-80. Corner of secondary road to house of F. L. Tucker and main road from Camagüey to Sola. Sample at same locality as sample DF-44-79, east of sample DF-44-78

A-228. Small cut on extension east of road from La Gloria to Central Jaronú, ½ mile east of main road from Sola to La Gloria. Area north of Sola

A-233. Quarry near Loma Gurugú, 5.8 kilometers north of Central Lugareño

A-243. Secondary road between Fincas El Peñón and Miranda, 120 meters south of road from Río Seco; north flank of eastward extension of Loma El Peñón, Sierra de Maragúan. Area east of Camagüey

A-244. Road to Antón, 3 kilometers north of Río Saramaguacán and about same distance south of Loma La Entrada, 1,325 meters southwest of Grúa Cuatro Caminos. Area south of Loma La Entrada

DF-44-129. Finca El Peñón, small limestone hill 660 meters south of Soler house, in direction of El Peñón hill

DF-44-130. North flank of Loma El Peñón, on Finca El Peñón, 1.5 kilometers south of Soler house. Area east of Camagüey

A-261. Finca La Caridad de Cangilones, secondary road to Cangilones, 1,350 meters west of junction Río Santa Cruz and Río Máximo, 350 meters north of Río Máximo

A-300. Lower part of Paso de Lesca in Sierra de Cubitas, 7 meters south of top of small hill south of main cliff, 80 meters north of serpentine breccia near overthrust fault

A-303. Lower part of Paso de Lesca, 57 meters north of sample A-300

A-307. Road to Río Seco, 105 meters east of secondary road of sample A-243. Area east of Camagüey

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RELATIONSHIP OF CRUDE OILS AND STRATIGRAPHY IN PARTS OF OKLAHOMA AND KANSAS[1]

RESEARCH COMMITTEE,[2] TULSA GEOLOGICAL SOCIETY
Tulsa, Oklahoma

ABSTRACT

An investigation of several hundred analyses of crude oils from several Paleozoic zones, ranging from the upper part of the Arbuckle limestone of Ordovician age to sands of Pennsylvanian age in northeastern Oklahoma and southeastern Kansas, shows the following results.

1. The oils from 43 pools investigated in the oil-bearing beds associated with the unconformity at the top of the Arbuckle limestone contain 31 classes or varieties of oil, and the oils from 22 pools in the beds associated with the unconformity at the top of the "Mississippi lime" contain 13 classes or varieties of oils; many classes in each of these two zones are represented by only one pool and the other classes by only a few pools.

2. The oils from 34 pools in the Bartlesville sand contain 6 classes of oil, but at least three of the classes are in sand lenses, called Bartlesville, that are of different age and lie at different stratigraphic positions; the oils from 16 pools in the Bartlesville sand, distributed through an area 30 miles long and 12 miles wide, fall in one class.

3. The oils from 33 pools in the Burbank sand, distributed through an area 150 miles long and 1 to 35 miles wide, fall in one class.

4. In Oklahoma each of seven oil-bearing zones younger than the Burbank sand and in Kansas each of four such zones contains a separate class of oil.

5. Each of four pools in the Squirrel (Prue) sand, which is one of the 7 zones mentioned under 4, contains a separate class of oil; inasmuch as the Squirrel (Prue) sand represents a series of lenses lying at various positions in a zone about 75 feet thick, the oil-bearing sands in the four pools probably are not precisely equivalent.

6. In each field wherein oil pools occur in several zones the oil of each zone is unlike the oil in the other zones.

7. The Bartlesville sand and the uppermost beds of the "Mississippi lime" contain similar oil in several pools in a narrow belt of country wherein the sand overlaps the "Mississippi lime."

These facts suggest that the environment of the source material may have determined the kind of oil of each oil pool. The local environment of beds in contact with the widespread unconformities at the top of the Arbuckle limestone and the top of the "Mississippi lime" were probably most variable; these beds contain the greatest variety of oils. The Burbank sand is confined to a thin stratigraphic zone; it was deposited in a narrow belt of country along the western shore of the Cherokee sea and the shoreline can be identified through a total length of about 150 miles. The environment during the time of deposition of the Burbank sand should have been similar all along the shore. It is significant, therefore, that the oil of all oil pools in the Burbank sand lenses of that belt are similar.

The structural movements that formed the many local domes, anticlines, synclines, and basins appear not to have changed the character of the oil, for the oil in the pools in the Burbank sand is similar throughout a distance of 150 miles wherein many types of folds are present. The present depth of burial likewise appears not to have altered the character of the oil, for the oil of the Burbank sand where it lies at a depth of 1,400 feet is similar to that found in the same sand at a depth of 2,900 feet or more. The low-gravity oils in several pools in the Arbuckle limestone in southeastern Kansas and in one pool in northeastern Oklahoma, that contain none of the lighter fractions common to most oils, have the appearance of weathered oils. They may have been weathered in post-Chattanooga time while the Chattanooga shale likely was being eroded from many small tracts and from at least one very large tract in northeastern Oklahoma and southeastern Kansas. The fact that the waters in the Arbuckle limestone in the area containing these pools appear to have been diluted by meteoric waters from the Ozark region has suggested to some that the oils were weathered by their contact with the waters.

[1] Manuscript received, May 10, 1946.

[2] Committee members: L. M. Neumann, chairman (geologist, Carter Oil Company), N. W. Bass (geologist, United States Geological Survey), R. L. Ginter (petroleum engineer, United States Geological Survey), S. F. Mauney (chemist, Carter Oil Company), T. F. Newman (geologist, Stanolind Oil and Gas Company), Charles Ryniker (geologist, Gulf Oil Corporation), and H. M. Smith (chemist, United States Bureau of Mines).

INTRODUCTION

An investigation of the relationship of crude oils and stratigraphy in parts of Oklahoma and Kansas has been under way intermittently for nearly 10 years by the research committee of the Tulsa Geological Society, a subcommittee of the American Association of Petroleum Geologists. The committee has studied the analyses of crude oils from several Paleozoic zones, ranging from the upper beds (Ordovician) of the Arbuckle limestone to sands in the Permian system in eastern Oklahoma and eastern Kansas. In addition, considerable study has been given crude oils of the Gulf Coast, Arkansas, Illinois, Michigan, New Mexico, western Kansas, and Colorado. The results reported in this paper represent only a part of the total data studied. The conditions in the area described are so diverse, however, that the paper presents much of the information revealed by the entire investigation. The paper includes many data about the oil in the Burbank sand that were presented previously.[3] In addition, during the time the investigation was in progress, most of the data revealed by the investigation were reported orally by members of the committee at the sessions of the research committee of the American Association of Petroleum Geologists, and at the main technical meetings during annual conventions of the Association.

The analyses of the crude oils were made at Bartlesville, Oklahoma, by the United States Bureau of Mines. Funds totalling about $2,000, that defrayed a part of the cost of making the analyses, were supplied from the research fund of the American Association of Petroleum Geologists.

COMPARISON OF CRUDE OILS

Crude oils are composed of gaseous and liquid hydrocarbons of an almost infinite variety having widely different quantitative relationships with each other. In addition to the hydrocarbons there are smaller quantities of organic compounds containing sulphur, nitrogen, and oxygen, and finally small quantities of inorganic materials.

Acceptance of the crude oil sample, as usually received by the laboratory for analysis, as representative of the crude oil in a given reservoir, carries with it certain assumptions that must be implicitly accepted. The first of these is that the loss of the normally gaseous hydrocarbons associated with the oil in the reservoir will not invalidate the data obtained on the liquid sample analyzed. The usual production methods, sampling procedures, and strength of the sample container preclude the collection of samples containing all the gaseous hydrocarbons associated with the oil, so that conclusions based on the analyses of the usual sample must include the assumption mentioned. A second assumption is that the "weathering" in the formation during the years of production has not altered the qualitative composition of the oil but may have changed somewhat

[3] L. M. Neumann, N. W. Bass, R. L. Ginter, S. F. Mauney, T. F. Newman, Charles Ryniker, and H. M. Smith, "Relationship of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), pp. 1801–09.

the quantitative relationships, and that such a change usually will be evident from the analytical data and can be given proper consideration by the person interpreting the analyses.

The identity or non-identity of crude oil samples is a very difficult point to decide in many instances. Probably the following *requirements*, if they could be evaluated, would suffice for showing the identity of two or more oils.

1. Virtual identity in the qualitative hydrocarbon composition
2. Virtual identity in the quantitative hydrocarbon composition
3. Virtual identity in sulphur content
4. Virtual identity in nitrogen and oxygen content
5. Virtual identity in inorganic content

Unfortunately, present analytical methods do not permit such a complete evaluation, and certain items, such as nitrogen, oxygen, and inorganic content, while they are determinable, are not available by methods that lend themselves to general application. It is possible, however, by relatively simple methods that can be applied uniformly to many samples, to make determinations which can be used as an alternative for the qualitative and quantitative composition value and also to determine the sulphur content. Such methods are typified by the analysis of crude oil by the Bureau of Mines Hempel method. All the analytical data on crude oils used in this report were obtained by this method. A brief discussion of this analytical procedure and its interpretation follows.

The Bureau of Mines Hempel method consists of distilling a 300-ml. charge of crude oil in prescribed apparatus under definite and carefully controlled conditions. The distillation is started at atmospheric pressure (approximately 760 mm. of mercury) and fractions (also called cuts) are taken as follows.

Fraction Number	*Cutting Temperature* °C.	°F.
1	50	122
2	75	167
3	100	212
4	125	257
5	150	302
6	175	347
7	200	392
8	225	437
9	250	482
10	275	527

The pressure of the distillation system is then reduced to 40 mm. of mercury and fractions 11 to 15 inclusive are obtained, the cutting temperature being 200°, 225°, 250°, 275°, and 300°C.

The following properties are determined on each fraction distilled at atmospheric pressure: (1) its volume (in percentage of the crude-oil sample); (2) its specific gravity at 60°/60°F.; (3) its correlation index (calculated from specific gravity and average boiling point).

As the fractions are cut at definite temperatures the boiling ranges of corresponding fractions from all distillations are virtually identical, except for the first fraction to distill over. Therefore, the average boiling point is virtually constant for corresponding fractions. The above properties are determined on each

"vacuum" fraction (fractions 11 to 15 inclusive) and, if possible, the cloud point and the viscosity at 100°F. also are determined. After the "vacuum" distillation

TABLE I

BUREAU OF MINES HEMPEL ANALYSIS OF CRUDE OIL

Louden field	Illinois
Bethel sand, Bethel or Benoist	Fayette County
1,550–1,566 feet	8N-3E-3rd

GENERAL CHARACTERISTICS

Specific gravity, 0.831	A.P.I. gravity, 38.8°
Sulfur, per cent, 0.26	Color, brownish black
Saybolt Universal viscosity at 100°F., 45 sec.	

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 748 mm. First drop, 27°C. (81°F.)

Fraction No.	*Cut at °C.*	*Cut at °F.*	*Per Cent*	*Sum Per Cent*	*Sp. gr. 60/60°F.*	*°A.P.I., 60°F.*	*C.I.*	*S.U. Visc., °F.*	*Cloud Test °F.*
1	50	122	4.1	4.1	0.640	89.6	—		
2	75	167	2.6	6.7	.665	81.3	5.1		
3	100	212	5.3	12.0	.711	67.5	17		
4	125	257	6.3	18.3	.738	60.2	21		
5	150	302	5.3	23.6	.757	55.4	22		
6	175	347	5.3	28.9	.775	51.1	24		
7	200	392	4.6	33.5	.792	47.2	26		
8	225	437	4.7	38.2	.807	43.8	27		
9	250	482	5.0	43.2	.820	41.1	28		
10	275	527	5.8	49.0	.833	38.4	30		
Distillation continued at 40 mm.									
11	200	392	3.0	52.0	0.848	35.4	33	40	10
12	225	437	5.5	57.5	.859	33.2	34	45	30
13	250	482	5.5	63.0	.872	30.8	37	58	50
14	275	527	4.9	67.9	.886	28.2	40	87	70
15	300	572	5.6	73.5	.897	26.3	43	165	85
Residuum			24.4	97.9	0.958	16.2			

Carbon residue of residuum, 10.8 per cent; carbon residue of crude, 2.6 per cent

APPROXIMATE SUMMARY

	Per Cent	*Sp. Gr.*	*A.P.I.*	*Viscosity*
Light gasoline	12.0	0.677	77.5	
Total gasoline and naphtha	33.5	0.732	61.8	
Kerosene distillate	9.7	.814	42.3	
Gas oil	13.8	.845	36.0	
Non-viscous lubricating distillate	9.4	.864–.888	32.3–27.9	50–100
Medium lubricating distillate	6.8	.888–.902	27.9–25.4	100–200
Viscous lubricating distillate	0.3	.902–.903	25.4–25.2	Above 200
Residuum	24.4	.958	16.2	
Distillation loss	2.1			

is completed the volume, specific gravity, and carbon residue percentage (by the Conradson method) of the residuum left in the distilling flask are determined.

In addition to the foregoing, the following properties of the crude oil are determined: (1) specific gravity at 60°/60° F.; (2) sulphur content; (3) saybolt viscosity at two temperatures, usually 77° and 100° F.; (4) carbon residue (by calculation from carbon residue of residuum).

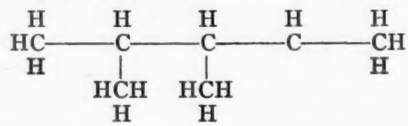
A complete Bureau of Mines Hempel method analytical report is shown in Table I. The analysis gives directly the volume percentage of material obtained within definite distillation temperatures. Because these percentages always relate to the same boiling range for a given fraction from any oil, they are a possible substitute for the quantitative hydrocarbon composition already cited as the No. 2 requirement for identifying crude-oil samples. However, they represent mixtures rather than individual hydrocarbons and must be used in conjunction with other data. The analysis does not give directly the qualitative picture but as hydrocarbons can to a considerable extent be typified by their specific gravities and boiling points a relationship of these properties could serve as a substitute for requirement No. 1 on qualitative hydrocarbon compositions. Such a relationship, developed early in this investigation because of this need, is called the "Correlation Index" (C.I.)[4] and is reported on the analysis sheet under the heading "C.I." Because no oils can be considered to be identical unless they contain the same hydrocarbons, this is the first and most important factor to be considered, and a further explanation of the correlation index and its meaning is essential.

Correlation index.—A study of possible relationships between the boiling points and specific gravities of hydrocarbons showed that if the reciprocal of the boiling point expressed in degrees Kelvin (°Centigrade+273.1) was plotted against the specific gravity for the normal paraffine hydrocarbons a linear relationship resulted. This line is shown in the extreme left of the chart on Figure 1. The normal paraffines all have a linear structure as exemplified by normal heptane.

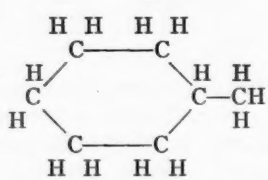
```
  H  H  H  H  H  H  H
 HC—C—C—C—C—C—CH
  H  H  H  H  H  H  H
```

An increase or decrease in molecular weight simply means a linear increase or decrease in chain length. When similar data for other hydrocarbons were plotted on the same basis they did not fall on a single line, but conformed to zones or groups. This is to be expected from the structure of the molecules. Each of the following hydrocarbons has the same number of carbon atoms as normal heptane.

Isoparaffine (2,3-dimethylpentane)

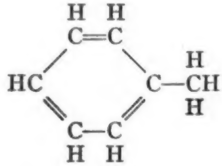


Naphthene (methylcyclohexane)



[4] H. M. Smith, "Correlation Index to Aid in Interpreting Crude-Oil Analyses," *U. S. Bur. Mines Tech. Paper 610* (1940).

Aromatic (toluene)



In each of these hydrocarbon types the substitution of a “$-\underset{H}{\overset{H}{C}}H$” group for an “H” can occur at any point on the molecule, resulting in different configurations, which in turn produce changes in properties that are not linear as for the normal paraffines. As a group the isoparaffines are found adjacent to the normal paraffine in Figure 1; farther to the right is a zone representing the naphthenes; and at the extreme right are the values for the aromatic hydrocarbons. The position of the data on this chart (Fig. 1) indicated that it would be possible to obtain an approximation of the composition of a material having a certain boiling point by drawing lines parallel with the one for the normal paraffines, and using the intercept of these lines on the temperature axis as an identifying number. To further simplify the system, the intercept for the normal paraffine line was arbitrarily given zero as the index number, and the intercept for the line through benzene an index number of 100. The interval between these two lines included virtually all hydrocarbons usually found in the analysis of crude oil. Figure 1 shows the constant index lines for every 10 units, and some data for different types of pure hydrocarbons. This index system can be applied easily to Hempel-analysis data, as each fraction (cut) has a constant average boiling point and an average specific gravity. Therefore, the calculation of this index for each fraction provides an indication of the type of material present, and comparison of index numbers for a series of fractions of two or more oils provides a usable substitute for the more exact qualitative analysis that would be desirable.

Further clarification of the use of the correlation index is shown by Figure 2, on which data for four crude oils are given. The curve shows the relationships between the correlation indexes for each fraction. The bar graph presents independent data obtained by quantitative analyses of Hempel fractions, and affords an opportunity to compare correlation indexes with the actual composition of the fractions in terms of hydrocarbon types.

For the first 10 fractions the curve for the Bradford oil does not rise above an index of 22, indicating a high content of normal and isoparaffinic material. This is verified by the analytical data showing more than 50 per cent paraffines. The Hastings oil is a great contrast to the Bradford oil; all except the index for fraction 2 are above 22, and reach a high of 47 for the fractions where analytical data are available. This curve would be interpreted to mean that the oil contained large quantities of naphthenes, and that this is true is shown by the bar graph,

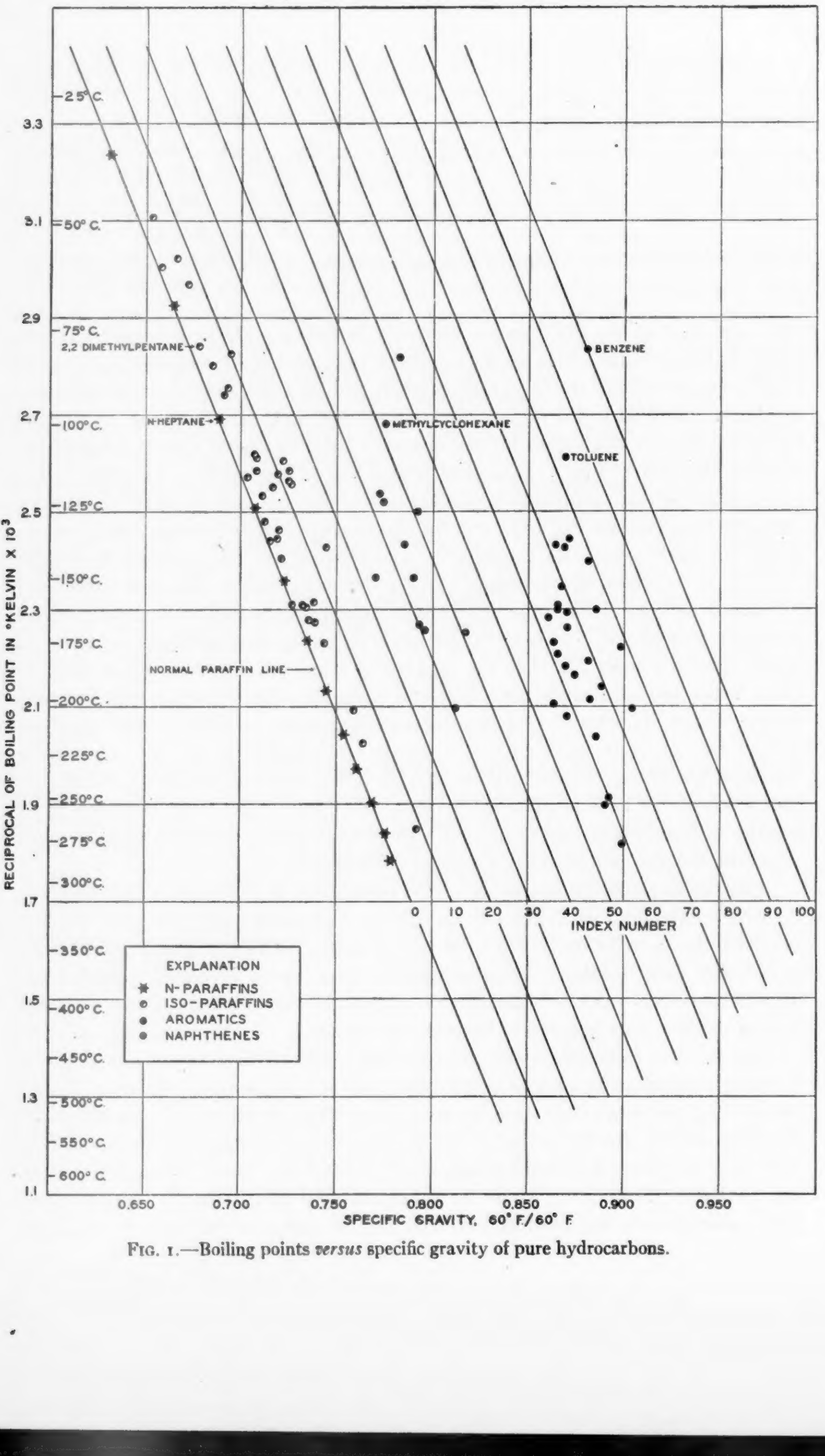


Fig. 1.—Boiling points *versus* specific gravity of pure hydrocarbons.

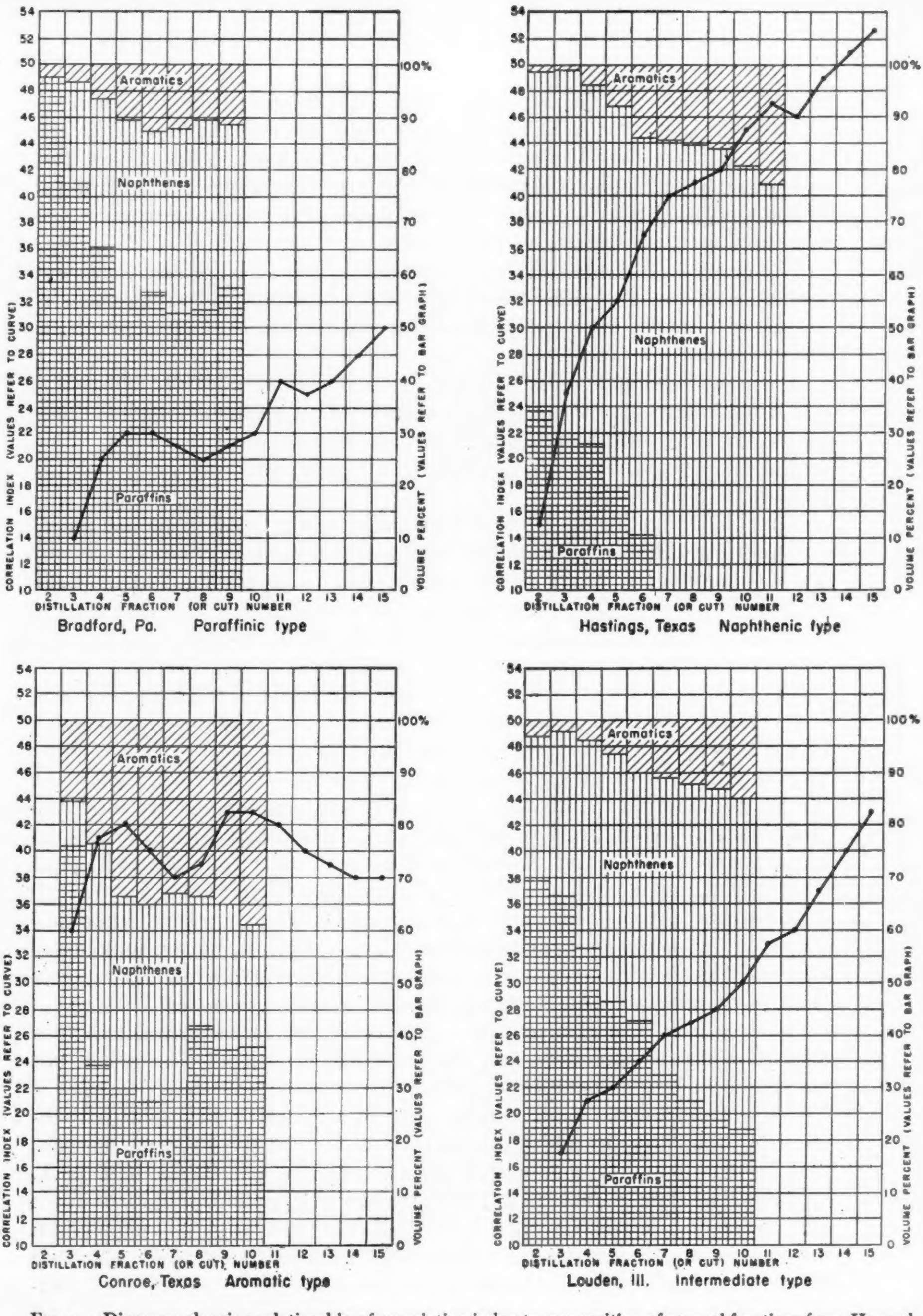


FIG. 2.—Diagrams showing relationship of correlation index to composition of several fractions from Hempel analysis of four crude oils. Composition expressed as volume percentage of paraffine, naphthene, and aromatic hydrocarbons comprising each fraction.

reaching a value of more than 80 per cent. The Conroe crude oil represents another type—one that is high in aromatic hydrocarbons. The "hump" in the index curve for fractions 4 and 5, especially when it has index values of more than 30, is generally indicative of high aromatic content. This supposition is borne out by the analytical data showing more than 30 per cent aromatics—a very high value for this type of hydrocarbon in crude oil.

The graph for Louden crude oil is typical of a great deal of Mid-Continent production and of the "intermediate type" oils. Paraffines and naphthenes decrease and increase, respectively, in a compensating degree, and the aromatic content is low.

From the foregoing discussion it follows that volume percentage figures and correlation indexes available from the Bureau of Mines Hempel analysis of crude oils can be used to meet requirements 1 and 2 for establishment of identity. They are not entirely satisfactory but by careful interpretation conclusions based on their use seem justified.

Classification of crude oils into types is not too difficult, as the differences are generally large. However, within a given type the differences are much smaller, and for some oils are difficult to differentiate from the experimental errors of the analysis. This is especially true of the oils of intermediate type, including most of the oils studied in this investigation. For such oils the interpreter of the analysis considers other characteristics which are available from the analytical report. Among these are sulphur content, percentage and gravity of residuum, viscosity of viscous fractions, and carbon residue of the crude oil. All of these factors have been considered when necessary to establish identity or non-identity of the crude oil in question. However, the first criteria considered are the correlation index curves, because if that is different for two oils then their non-identity is at once established. To aid in this the experimental error that normally can be expected is taken into consideration. A single analysis may differ from the average of several for the same oil by the following approximate limits: fraction 2 through 8 ± 0.5 index number; fraction 9 through 12 ± 1.0 index number; fraction 13 through 15 ± 1.5 index number. However, these values can not be applied too vigorously, as the wide divergence of a single value is probably experimental error and the general trend of the curve must be given much consideration.

In interpreting the analyses used in the present report, some crude oils were difficult to classify definitely, but their inclusion in another class would not materially change the conclusions reached.

Osage County, Oklahoma, and the area adjacent to it, are particularly interesting for an investigation of the oils because oil pools occur there in 20 zones that are distributed through a stratigraphic sequence about 2,000 feet thick, ranging in age from Ordovician to Pennsylvanian (Fig. 3). In many places in the area several oil-bearing zones occur in the same field. Most ot the oil samples from this area, however, were obtained from one of the following four zones, which are the zones that have accounted for most of the oil produced: (1) the Arbuckle lime-

stone and Hominy sand, (2) the "Mississippi lime" and Burgess sand, (3) the Bartlesville sand, and (4) the Burbank sand. Several oil samples were obtained from each of many other zones. The oils from the various fields of the area are discussed by the zones in which they occur, beginning with the oldest.

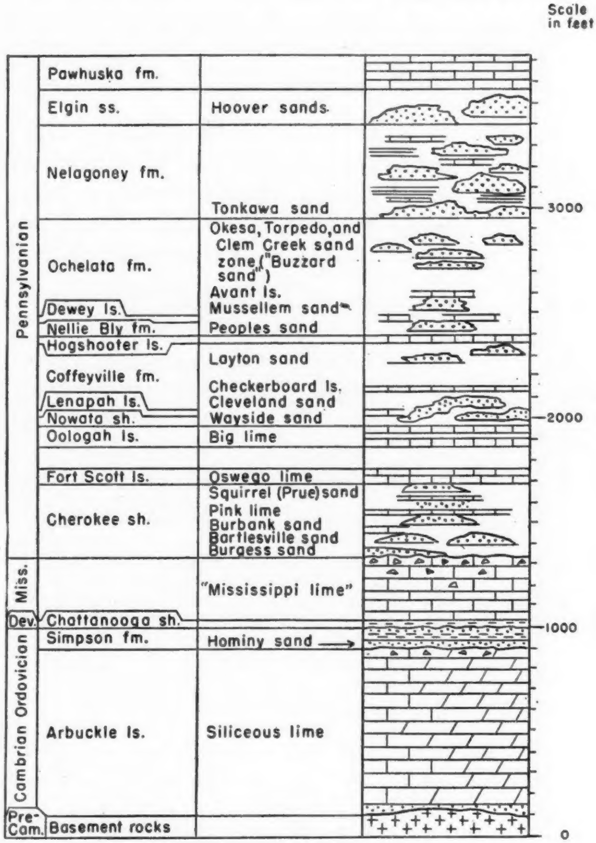


FIG. 3.—Generalized columnar section of a part of the rocks in Osage County, Oklahoma.

OIL POOLS IN ARBUCKLE LIMESTONE AND HOMINY SAND IN OSAGE AND TULSA COUNTIES, OKLAHOMA

Oils from 29 pools in southeastern Osage County and one pool near the north margin of Tulsa County, whose oil is in the Arbuckle limestone or the Hominy sand, were analyzed for this investigation. In all, 18 classes of oil are present in the 30 pools (Table II). Moreover, it appears likely that an even greater variety of oils

TABLE II

CORRELATION-INDEX NUMBERS AND OTHER FACTORS OF ANALYSES OF CRUDE OILS FROM ARBUCKLE LIMESTONE AND HOMINY SAND FOR 29 POOLS IN OSAGE COUNTY AND ONE POOL IN TULSA COUNTY, OKLAHOMA

Class of Oil	Pool Name	Oil-Bearing Beds	Location Secs. T. R.	Number of Analyses	Distillation at Atmospheric Pressure: 3 (75°–100°)	4 (100°–125°)	5 (125°–150°)	6 (150°–175°)	7 (175°–200°)	8 (200°–225°)	9 (225°–250°)	10 (250°–275°)	Vacuum Distillation at 40 Millimeters: 11 (Up to 200°)	12 (200°–225°)	13 (225°–250°)	14 (250°–276°)	15 (275°–300°)	Crude Oil: A.P.I. Gravity of Crude	Sulphur Content of Crude, Per Cent	Carbon Residue of Crude, Per Cent	Residuum: Residuum, Per Cent	A.P.I. Gravity of Residuum
			Fraction (or Cut) Number → Distillation Temperature °C.																			
1	Flat Rock (middle)	Hom.	31-21-12	1	9	12	15	18	21	24	25	28	33	35	38	41	42	51.3	0.10	0.5	4.5	17.5
2	Sand Springs	Arb. or Hom.	15-19-11	1	14	16	17	19	22	24	27	29	35	36	38	40	43	36.8	0.19	1.5	19.0	16.7
3	Flat Rock (north)	Hom.	19-21-12	1	13	16	18	21	23	25	27	30	33	34	37	40	43	40.9	0.13	1.2	14.9	17.3
4	Country Club	Arb.	28-20-12	1	13	17	19	22	24	26	29	32	36	37	39	41	43	38.6	0.18	1.4	17.7	17.3
	Branstetter	Arb.	28-22-11	1	13	18	20	23	25	27	30	32	34	35	37	41	43	40.4	0.22	1.2	15.1	17.3
5	Reese Dillard	Hom. and Arb.	25-22- 9	1	15	18	21	23	26	28	29	32	34	35	38	39	40	40.9	0.12	0.9	16.4	19.4
	South Canyon	Arb.	32-23-10	3	15	18	21	22	26	28	29	31	35	35	37	39	40	40.1	0.13	1.1	17.5	19.7
	North Gilliland	Arb.	12, 14-23- 7	3	15	18	20	23	25	27	28	29	35	35	38	40	40	39.4	0.13	0.9	18.0	20.4
6	South Wildhorse	Arb.	11-21-10	2	16½	19½	22	25	26	28	30½	32½	37	37½	39½	39½	41	39.5	0.15	1.1	17.7	19.6
	Hominy	Arb.	13-22- 8	1	17	20	23	25	27	29	30	31	36	36	38	40	41	40.6	0.13	1.0	17.2	19.5
	Bandwheel	Arb.	6-23- 9	1	14	19	22	25	27	29	31	32	34	35	36	39	40	40.6	0.15	1.6	17.3	20.8
10	South Dalton	Arb. and Hom.	18-24- 8	6	17	20	23	26½	29	30	31	33	35	35	38½	41	42	40.3	0.17	1.0	17.1	19.8
7	Wildhorse	Arb.	34-22-10	1	18	21	24	27	29	30	31	33	37	37	39	38	40	39.0	0.15	1.1	18.8	20.2
8	Gilliland (middle)	Arb.	23-23- 7	1	17	21	23	26	28	31	32	34	37	37	39	40	41	38.6	0.13	0.8	18.5	21.1
	Gilliland (south)	Arb.	25-23- 7	1	18	21	23	27	28	31	32	35	37	37	39	41	40	38.0	0.16	0.9	20.8	21.6
	South Naval Reserve	Arb.	9, 16-23- 7	2	15½	20	23½	27	29½	31½	33½	35½	38	36½	39	40	43	36.2	0.17	1.2	22.5	21.5
	Naval Reserve	Hom. or Arb.	22-24- 7	1	17	21	24	28	30	32	35	36	39	37	39	42	41	37.8	0.19	1.0	22.7	21.5
9	Boston	Arb.	1-21- 7	1	—	22	24	26	29	30	32	34	37	37	40	44	43	34.4	0.16	1.3	21.6	20.2
	North Boston	Arb.	25-22- 7	2	17	20	23	25½	28½	30	31	33½	37½	37½	40½	43	42	36.0	0.14	1.2	21.9	20.7
	West Boston	Hom.	34-22- 7	2	16½	20	21½	24½	27½	29½	31	33½	37	37½	41	42	43	36.8	0.15	1.3	24.0	19.6
7	Falls Dome	Arb.	34-24- 8	1	18	21	24	27	30	32	34	35	37	39	42	42	45	37.8	0.19	1.4	21.1	19.4
11	Hominy Falls	Arb.	36-22-11	1	15	19	21	23	28	30	32	34	36	38	40	41	43	35.8	0.14	1.8	25.9	19.5
12	Flat Rock (south)	Arb. or Hom.	8, 9-20-12	2	12½	17	18½	21	23½	26	27½	30	32	31½	35½	38	39	40.5	0.18	1.0	16.4	19.3
	East Madalene	Arb.	23-21-10	1	13	18	20	22	24	25	27	28	33	33	33	35	40	39.4	0.16	1.0	17.1	20.5
13	Shell Creek	Arb.	29-20-11	1	16	18	21	25	27	30	31	34	39	43	46	49	53	40.2	0.21	1.4	15.1	15.9
14	Turkey Creek	Arb.	10-20-11	2	15	18	21	24	25½	26½	27½	28½	33	34	38	41½	47	40.1	0.23	1.1	18.8	18.4
	Wimberley	Arb. and Hom.	21, 28-20-11	2	15	18½	22	25	26½	26½	27½	29	32½	34	38	42	45½	38.5	0.23	1.2	18.1	19.0
15	Canyon	Arb.	17, 20-23-10	3	14	18	22	26	30	34	36	39	43	43	45	46	47	32.1	0.24	1.9	32.3	19.8
16	East Hominy	Arb.	16-22- 9	1	18	21	24	28	32	35	38	38	39	38	41	41	42	32.1	0.17	1.3	32.0	21.1
17	Shell Creek	Hom.	29-20-11	1	18	22	25	27	29	29	29	30	33	35	40	46	47	38.4	0.23	1.3	16.4	18.4
18	No name	Hom.	2-22- 7	1	—	18	19	22	23	25	26	28	31	32	33	35	37	39.8	0.20	1.0	16.8	21.1

than 18 is present in the Arbuckle limestone and Hominy sand in the area, for the analyses represent oils from only about two-fifths of the pools. The great variety of oils occurring in these formations in this small area constitutes one of the most noteworthy facts revealed by the investigation.

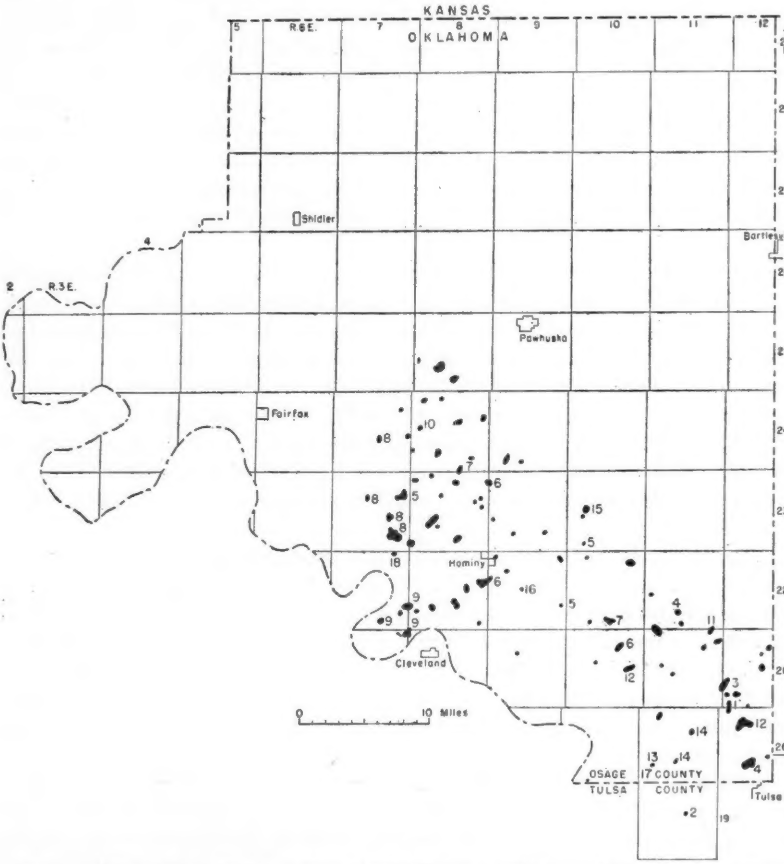


FIG. 4.—Map of Osage County and part of Tulsa County, Oklahoma (after *U. S. Geol. Survey Bull. 900*), showing oil pools and classes of oil in Arbuckle limestone and Hominy sand. Numbers beside pools indicate classes of oil shown in Table II.

One interesting group of oils is represented by classes 1 through 8. It represents a series of crude oils that are all of the intermediate type, and the differences between any two adjacent classes are generally so small that differentiation would not be warranted. However, for fractions 2 through 10 there seems to be a definite increase in naphthenicity in going from class 1 to class 8. In contrast to this

change for the more volatile parts of the oil, the less volatile parts, represented by fractions 11 through 15, are all very similar. The differences and similarities mentioned are apparent in Figure 5, which shows the correlation index curves for classes 1 to 6 and class 8. Classes 9 and 10 also may belong to this group, but their heavy fractions are somewhat different from those of the group.

The remaining oils, classes 11 to 18 inclusive, show little conformity to each other or to the oils in the first 10 classes, as is apparent in Figure 6. Some, including class 18, are more paraffinic than others; some, including classes 13, 15, 16, and 17, are more naphthenic than others; and classes 11 and 14 are variable. It is noteworthy that the four classes, 13, 14, 15, and 17, that appear to be most naphthenic in the heavy ends, contain more sulphur (Table II) than most of the other oils. There are exceptions to this sulphur relationship, however; for example, the oils of classes 4 and 18 contain more sulphur than most of the other oils.

The oils from the Arbuckle limestone and Hominy sand show considerable differences even between pools that are near each other. For example, the South Canyon and Canyon pools, lying only 2½ miles apart in the southwestern part of T. 23 N., R. 10 E. (Fig. 4) have different oils (classes 5 and 15); the North Gilliland pool in Secs. 12, 13, and 14, T. 23 N., R. 7 E., has different oil (class 5) than other pools 2 to 4 miles south and west of it, and other pools 5 to 6 miles northeast of it; and the oil in the unnamed pool in Sec. 2, T. 22 N., R. 7 E., is definitely different than that in the pools of T. 23 N., R. 7 E.; the oils in T. 20 N., R. 11 E., are distinctly different than oils from pools a few miles south and east of them.

The area of each oil pool in the Arbuckle limestone or the Hominy sand is, as a rule, less than half a square mile. All oil pools are associated with salt water and much water is produced with the oil soon after production starts. The oil in the Arbuckle limestone occurs in porous dolomite in the top 25 feet of the limestone, and the oil in the Hominy sand occurs in beds of sandstone or dolomitic and limy sandstone. Inasmuch as the Arbuckle limestone was exposed to erosion prior to its burial by younger beds it is probable that different beds form the top of the formation in different pools.

Beds in the Simpson formation, including the Hominy sand, are in contact with the top of the Arbuckle limestone and, therefore, directly overlie its oil-bearing beds or are separated from them by a small interval, but it is probable that beds of different age in the Simpson formation are in contact with the Arbuckle limestone in different pools. The Simpson formation in southern Osage County forms a thin wedge tapering northeastward; it pinches out along a northwesterly trending line that passes about 14 miles north of Tulsa and 10 miles south of Pawhuska. In Osage County all known oil pools, except one, in the Arbuckle limestone or in the Hominy sand are in the southeastern third of the county, in the area that contains the Simpson formation. One small pool in the Arbuckle limestone, a few miles south of the Kansas line and in the area wherein the Simp-

son is absent, contains heavy black oil that is distinctly unlike the oil elsewhere in the county. The oil of this pool is similar to oils in several pools in southeastern

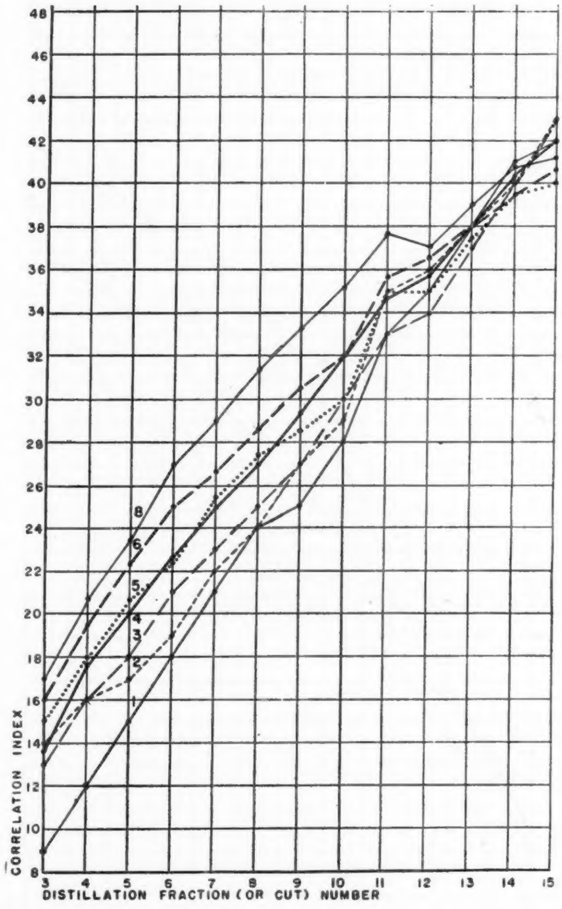


FIG. 5.—Curves showing correlation-index numbers of crude-oil classes 1 to 6 and 8 in Arbuckle limestone and Hominy sand in Osage and Tulsa counties, Oklahoma. Numbers on curves indicate classes. (See Table II for detailed data and classes.)

Kansas and so is described in the chapter on the oil pools in the Arbuckle limestone in southeastern Kansas.

Most oil pools in these formations are on the crests of small domes; a few pools, however, are high on the flanks of domes whose crests are barren of oil. The dips

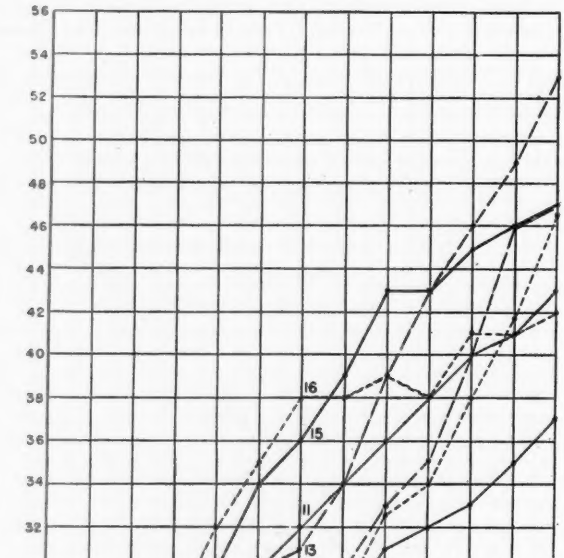


FIG. 6.—Curves showing correlation-index numbers of crude oil classes 11 and 13 to 18 in Arbuckle limestone and Hominy sand in Osage County, Oklahoma. Numbers on curves indicate classes. (See Table II for detailed data and classes.)

of the beds in the Arbuckle limestone and in the Hominy sand on all domes are steeper than the dips of the younger beds. So far as the writers know, the rocks in all parts of the area containing oil pools in the Arbuckle limestone or in the Hominy sand have been deformed similarly. The beds have been folded into gently dipping domes, anticlines, basins, and synclines. Deformation that affected these oil-bearing beds began in the Ordovician period and continued intermittently, at least through the Permian.

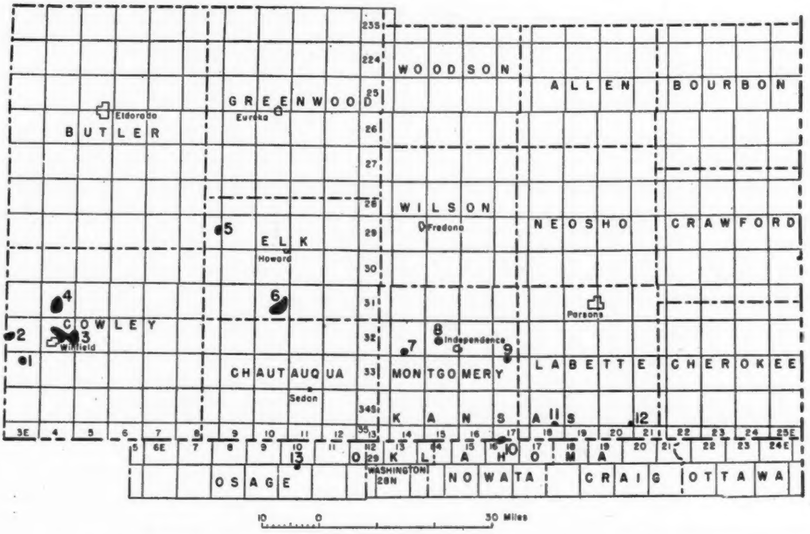


FIG. 7.—Map of southeastern Kansas and margin of northeastern Oklahoma, showing oil pools and classes of oil in Arbuckle limestone for which analyses are available. Numbers beside pools indicate classes of oil shown in Table III: 1, Graham; 2, Slick-Carson; 3, Winfield; 4, Hittle; 5, Porter; 6, Moline; 7, Lamb; 8, Clemmer; 9, Bellaire; 10, Coffeyville; 11, Edna; 12, Chetopa; 13, Pond Creek.

OIL POOLS IN ARBUCKLE LIMESTONE IN SOUTHEASTERN KANSAS AND ONE POOL IN NORTHEASTERN OKLAHOMA

Oils from 12 pools in southeastern Kansas and one pool in northeastern Osage County, Oklahoma, whose oil is in the Arbuckle limestone, were analyzed for this investigation. The location of the pools is shown on Figure 7; many of the data obtained by the analyses are shown in Table III. Each pool contains a separate class of oil. The oils in Cowley County, Kansas, are of the same general type as the oils in the Arbuckle limestone and Hominy sand in southeastern Osage County, Oklahoma. The curve of the correlation indexes of the oil from the Hittle pool of Kansas (Fig. 8), although in a lower position on the graph, has the same general trend as that for oil from the Arbuckle limestone in the Shell Creek pool (class

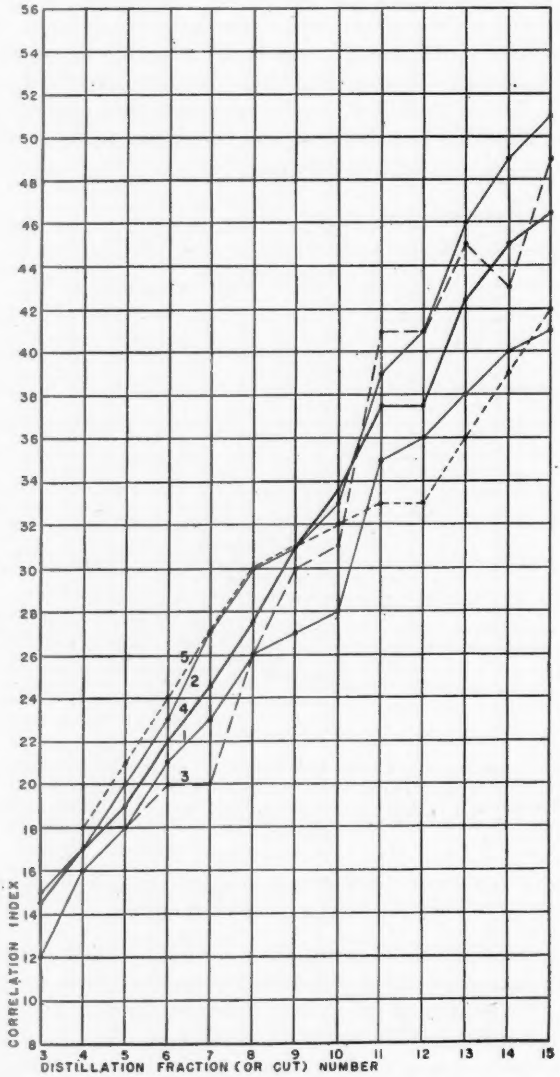


FIG. 8.—Curves showing correlation-index numbers of crude oil classes 1 to 5 in Arbuckle limestone in Cowley and Elk counties, Kansas. Numbers on curves indicate classes. (See Table III for detailed data and classes.)

13) of Oklahoma (Fig. 6). The oil of the Hittle pool is more paraffinic throughout all fractions than the oil of the Shell Creek pool, however. The curve for the oil from the Slick-Carson pool of Kansas is very similar to the curve for the oil from the Arbuckle limestone at Shell Creek. The gravity of the Slick-Carson oil is less and the percentage of residuum is much less than for the oil from Shell Creek. The curves of the correlation indexes for the oils of the Graham and Winfield pools of Kansas fall in the general position of classes 2, 4, and 12 of the oils from the Arbuckle limestone and Hominy sand of southeastern Osage County, Oklahoma. The average gravity of the oils of the Cowley County, Kansas, pools is about equal to, and the percentage of sulphur is higher than, that of the Oklahoma oils, however.

The oils of the pools in Elk, Montgomery, and Labette counties, Kansas, and the single pool in northeastern Osage County, Oklahoma, are different in type than the oils in Cowley County, Kansas, and southeastern Osage County, Oklahoma. These southeastern Kansas oils are characterized (1) by having a low A.P.I. gravity, ranging from 18.2° to 28.8°, shown in Table III, (2) by large sulphur content, ranging from 0.33 to 0.68 per cent, (3) by a relatively large percentage of residuum and a relatively large percentage of carbon residue of the crude, (4) by containing no light materials that distill off in the first 5 to 8 fractions, and (5) by being highly naphthenic and aromatic. The graphs of the correlation indexes (Fig. 9) show that each pool contains a separate class of oil and that there is a wide range in the character of the oils.

All these Kansas oil pools and the single pool in northeastern Osage County, Oklahoma, are in the uppermost few feet of the Arbuckle limestone, situated on small relatively steeply folded domes. It may be important that the pools in Cowley County, Kansas, lie close to the margin of the Simpson formation; the Graham pool, according to McClellan's[5] map, lies inside the Simpson margin and therefore has a thin wedge of Simpson beds overlying the Arbuckle; the other pools lie a short distance outside the margin of the Simpson, according to McClellan's map, and have Chattanooga shale in contact with the Arbuckle. Inasmuch as the oils of Cowley County are similar to the oils in the Arbuckle limestone and Hominy sand of southern Osage County, Oklahoma, where beds of the Simpson formation (including the Hominy sand) are in contact with the Arbuckle, the suggestion is apparent that beds of the Simpson formation may be the source beds for the oil of all these pools. The heavy oils in the Arbuckle limestone in southeastern Kansas and in the single pool in northeastern Osage County, Oklahoma, are in a broad region wherein the Simpson formation is absent. There, either the Chattanooga shale or the "Mississippi lime" is in contact with the Arbuckle limestone. Moreover, it appears probable that the Arbuckle beds that yield oil in the pools near the Simpson margin are probably absent in the south-

[5] H. W. McClellan, "Subsurface Distribution of Pre-Mississippian Rocks of Kansas and Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 12 (December, 1930), Fig. 2, p. 1542.

TABLE III

CORRELATION-INDEX NUMBERS AND OTHER FACTORS OF ANALYSES OF CRUDE OILS FROM ARBUCKLE LIMESTONE FOR 12 POOLS IN SOUTHEASTERN KANSAS AND ONE POOL IN NORTHEASTERN OKLAHOMA

				Distillation at Atmospheric Pressure								Vacuum Distillation at 40 Millimeters					Crude Oil			Residuum	
		Fraction (or Cut) Number		3	4	5	6	7	8	9	10	11	12	13	14	15					
Class of Oil	Pool Name	Distillation Temperature °C. Location Sec. T. R.	Number of Analyses	75°–100°	100°–125°	125°–150°	150°–175°	175°–200°	200°–225°	225°–250°	250°–275°	Up to 200°	200°–225°	225°–250°	250°–275°	275°–300°	A.P.I. Gravity of Crude	Sulphur Content of Crude, Per Cent	Carbon, Residue of Crude, Per Cent	Residuum, Per Cent	A.P.I. Gravity of Residuum
1	Graham	9-33S- 3E Kans.	1	12	16	18	21	23	26	27	28	35	36	38	40	41	38.8	0.15	1.2	17.6	18.6
2	Slick-Carson	19-32S- 3E Kans.	1	15	17	20	23	27	30	31	33	39	41	46	49	51	35.6	0.20	1.5	11.8	12.3
3	Winfield	22-32S- 4E Kans.	1	—	18	18	20	20	26	30	31	41	41	45	43	49	34.8	0.29	1.8	17.6	15.4
4	Hittle	21-31S- 4E Kans.	2	14½	17	19	22	24½	29½	31	33½	37½	37½	42½	45	46½	39.2	0.22	1.4	15.4	15.2
5	Porter	13-29S- 8E Kans.	1	—	18	21	24	27	30	31	32	33	33	36	39	42	33.6	0.41	1.9	22.5	17.0
6	Moline	23-31S-10E Kans.	1	—	—	—	29	31	33	32	33	36	35	35	36	40	28.8	0.38	2.5	28.5	16.8
7	Lamb	33-32S-14E Kans.	1	—	—	—	—	—	—	25	27	33	34	37	40	41	28.2	0.56	2.7	30.7	16.5
8	Clemmer	21-32S-15E Kans.	1	—	—	—	—	—	—	41	43	48	49	51	53	55	18.2	0.68	7.7	45.6	11.1
9	Bellaire	4-33S-17E Kans.	2	—	—	—	—	36	39	39	38½	40	40	43	46	48	23.7	0.56	4.2	37.5	14.0
10	Coffeyville	17-35S-17E Kans.	1	—	—	—	—	40	42	42	42	44	45	48	51	51	24.2	0.58	2.6	37.0	16.4
11	Edna	35-34S-18E Kans.	1	—	—	—	—	—	37	39	38	42	43	46	48	50	24.0	0.58	2.3	40.9	17.5
12	Chetopa	36-34S-20E Kans.	1	—	—	—	—	32	37	39	38	42	43	47	51	54	24.3	0.51	2.3	33.5	15.4
13	Pond Creek	3-28N-10E Okla.	1	—	—	26	32	36	39	40	40	42	42	46	47	48	26.1	0.33	2.8	39.0	17.9

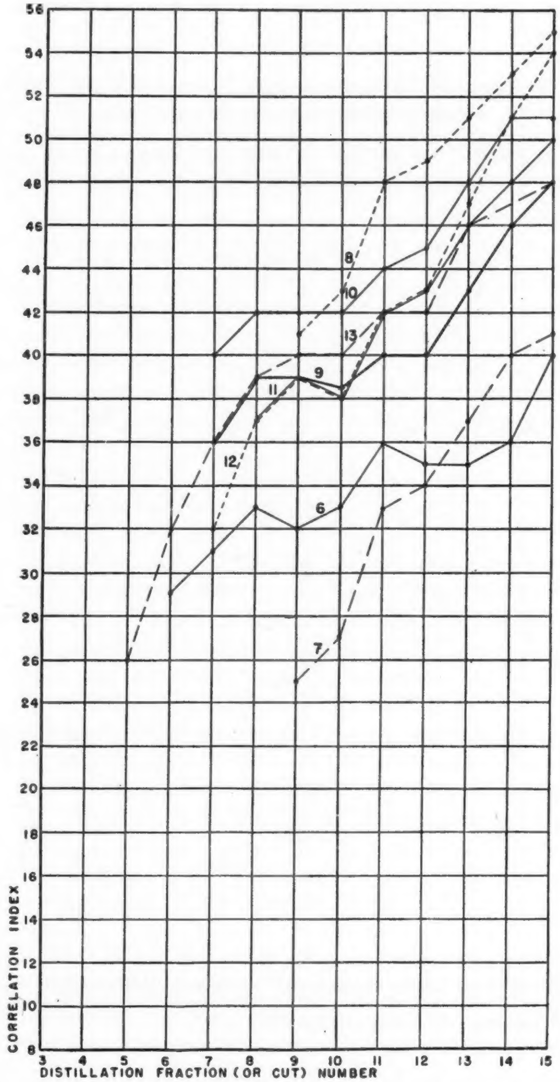


FIG. 9.—Curves showing correlation-index numbers of crude oil classes 6 to 13 in Arbuckle limestone in southeastern Kansas and one pool in Osage County, Oklahoma. Numbers on curves indicate classes. (See Table III for detailed data and classes.)

eastern Kansas area and that older beds of the Arbuckle form the top of the formation there.

OIL POOLS IN "MISSISSIPPI LIME," BURGESS SAND, AND BURGESS SAND-"MISSISSIPPI LIME" ZONE

Oils from 19 pools in the eastern two-thirds of Osage County and three pools near the western margin of Tulsa County (Fig. 10) whose oil is in either the

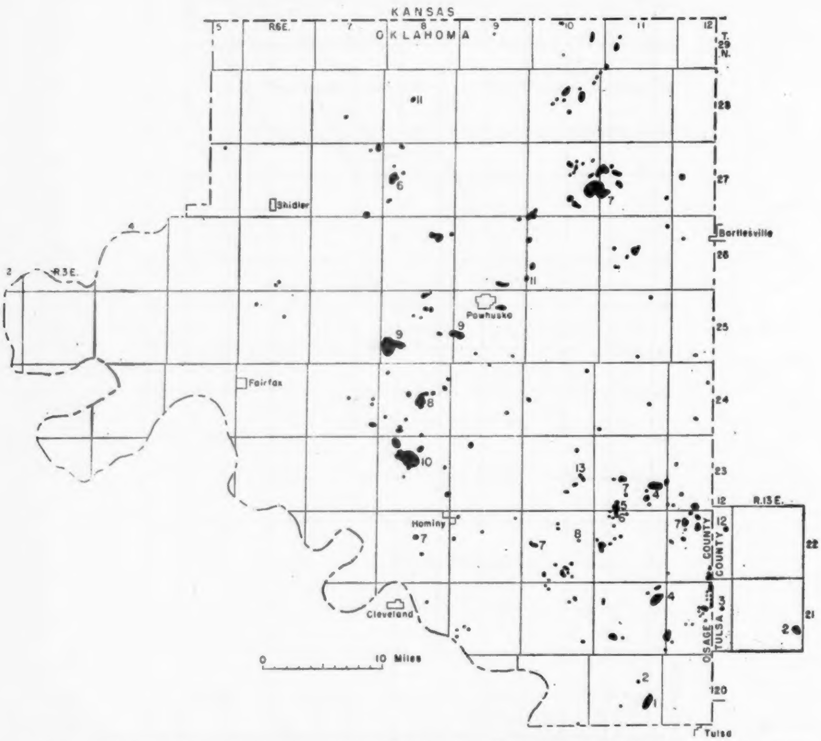


FIG. 10.—Map of Osage County and part of Tulsa County, Oklahoma (after *U. S. Geol. Survey Bull. 900*), showing oil pools and classes of oil in "Mississippi lime" and Burgess sand. Numbers beside pools indicate classes of oil shown in Table IV.

"Mississippi lime," the Burgess sand, or the thin zone embracing the contact of these two formations, were analyzed for this investigation. A total of 13 classes of oil is present in the 22 pools (Table IV). Moreover it appears certain that a much greater variety of oils than 13 is present in these beds in the area, for the

analyses available represent oils from only about one-fifth of the pools. Like the oil in the Arbuckle limestone and the Hominy sand, the great variety of oils in the "Mississippi lime" and the Burgess sand constitute one of the most noteworthy facts revealed by this investigation. Except for the oils of classes 1, 2, 4, 5, 12 and 13, the differences between the classes, however, are not as pronounced as between the classes of oil from the Arbuckle and Hominy.

Correlation indexes for the 13 classes of this group of oils are shown graphically by curves in Figures 11 and 12. The correlation indexes and several other factors for the oils are given in Table IV. Class 1 oil is the most paraffinic of all 13 classes, and class 2 oil differs only slightly from it. Several classes show only minor differences between each other; for example, except for small differences in the vacuum fractions, classes 8, 9, and 10 are very similar, and classes 6 and 3 are not widely different from them. Classes 4 and 5 are readily differentiated, and except for classes 12 and 13 are the most naphthenic of all classes. Classes 12 and 13 are distinct and different from the other classes, although class 4 has a marked resemblance to class 12. The pools of the several classes of oil are distributed for the most part unsystematically throughout the region. The area containing the pools of naphthenic oils of classes 4 and 5 are virtually surrounded by areas producing paraffinic oils.

The oil pools in these beds occupy two and possibly three northeastward-trending belts of country lying about 15 miles apart (Fig. 10). One belt is in the southeasternmost part of Osage County and extends into the western part of Tulsa County and the southwestern part of Washington County. There, some oil pools are in the Burgess sand, some are in the uppermost weathered part of the "Mississippi lime," and some are in a zone that includes parts of both these formations. The Burgess sand occurs in lenticular bodies in contact with the "Mississippi lime" or locally is separated from it by a bed of shale or sandy shale only a few feet thick. In some pools whose wells were drilled many years ago, the records are not clear as to whether the oil-bearing bed is in the Burgess sand or in the "Mississippi lime"; accordingly, the term Burgess sand-"Mississippi lime" zone is used herein to designate the oil-bearing beds in such pools as well as in the pools where it is known that the oil actually occurs in both the sand and the underlying limestone.

The second belt of country containing oil pools in these rocks is about 15 miles wide and passes through Pawhuska. This area lies northwest of the area containing the true Burgess sand. There the oil occurs in the top weathered beds of the "Mississippi lime." The oil-bearing zone, for the most part, is composed of beds of weathered chert. It is possible that in some places the chert was transported in early Pennsylvanian time, but such chert can not be separated readily from chert that was weathered in place. Locally, however, the Bartlesville sand is in contact with the "Mississippi lime" and oil is present in the sand and in the underlying limestone. This condition is present, for example, in the Osage-

TABLE IV

CORRELATION-INDEX NUMBERS AND OTHER FACTORS OF ANALYSES OF CRUDE OILS FROM "MISSISSIPPI LIME," BURGESS SAND, AND BURGESS SAND-"MISSISSIPPI LIME" ZONE FOR 19 POOLS IN OSAGE COUNTY AND 3 POOLS IN TULSA COUNTY, OKLAHOMA

					Distillation at Atmospheric Pressure								Vacuum Distillation at 40 Millimeters					Crude Oil			Residuum	
			Fraction (or Cut) Number		3	4	5	6	7	8	9	10	11	12	13	14	15					
Class of Oil	Pool Name	Oil-Bearing Beds	Distillation Temperature °C. Location Secs. T. R.	Number of Analyses	75°–100°	100°–125°	125°–150°	150°–175°	175°–200°	200°–225°	225°–250°	250°–275°	Up to 200°	200°–225°	225°–250°	250°–275°	275°–300°	A.P.I. Gravity of Crude	Sulphur Content of Crude, Per Cent	Carbon Residue of Crude, Per Cent	Residuum, Per Cent	A.P.I. Gravity of Residuum
1	Page, south	Burg. sd.-"Miss. lime" zone	23-20-11	1	12	17	20	23	25	26	26	27	31	30	33	36	38	41.1	0.21	1.2	18.6	18.7
2	Page, middle	Burg. sd.-"Miss. lime" zone	15-20-11	1	14	18	21	23	25	27	27	29	33	33	36	38	39	37.2	0.20	1.6	23.6	19.4
	Owasso	Burg. sd.	25-21-13	2	18	19	20½	22½	24	26	27	28	32	32	35½	36½	39½	37.2	0.22	1.3	20.0	18.5
3	Bird Creek	Burg. sd.	13-21-12	1	18	22	25	27	28	29	30	32	36	36	37	40	40	37.6	0.16	1.3	24.9	20.0
4	Hominy Falls	Burg. sd.-"Miss. lime" zone	11-21-11	1	15	21	26	30	31	32	32	32	38	37	40	41	43	32.3	0.20	2.2	31.2	19.4
	Avant	Burg. sd.-"Miss. lime" zone	24, 26-23-11	2	12	22½	26½	30	31	32	31½	32½	37	37	39	41	41	34.6	0.16	1.4	23.4	20.0
5	West Avant	Burg. sd.-"Miss. lime" zone	5-22-11	1	16	23	24	27	30	32	33	34	37	37	39	40	40	34.6	0.19	1.4	27.1	20.7
6	West Avant	Burg. sd.-"Miss. lime" zone	5-22-11	1	15	20	23	26	28	30	31	33	38	37	39	41	42	35.6	0.15	1.2	23.0	20.2
	Pearson Junction	"Miss. lime"	18-27- 8	2	16	18½	22	25½	28	30½	32	34	37	36½	39½	40½	41½	38.4	0.14	1.0	21.1	20.7
7	Skiatook	Burg. sd.	5, 8-22-12	1	13	20	22	24	26	27	28	30	35	35	37	39	40	35.4	0.16	1.4	23.7	19.8
	West Avant	Burg. sd.-"Miss. lime" zone	28-23-11	1	13	18	21	24	26	28	29	31	35	34	37	40	40	38.4	0.14	1.1	22.0	21.0
	North Wildhorse	"Miss. lime"	18-22-10	1	—	19	24	25	26	26	29	31	36	35	37	39	39	33.6	0.15	1.4	26.0	20.5
	West Hominy	"Miss. lime"?	15-22- 8	1	17	20	23	25	27	29	31	32	35	35	37	39	39	39.0	0.19	0.9	21.9	21.0
	Domes	"Miss. lime"	18-27-11	2	15	19	21½	24½	26½	27½	28½	29½	34½	33½	36½	37½	38	36.4	0.20	1.6	22.5	19.0
8	East Wildhorse	"Miss. lime"	14-22-10	1	17	20	23	25	27	28	30	32	35	37	37	40	41	39.0	0.13	1.1	21.0	20.5
	Tidal-Osage	"Miss. lime"	15, 22-24- 8	2	13	21	22½	26	28	29½	31	32	36½	36	38½	40	41	38.2	0.16	1.1	20.1	19.5
9	Atlantic	"Miss. lime"	30-25- 8	1	18	21	23	25	26	28	29	31	35	34	37	38	38	42.3	0.13	0.8	16.6	20.7
	New England	"Miss. lime"	19-25- 9	1	18	22	24	26	27	29	30	32	36	36	37	39	39	42.1	0.12	0.8	15.8	20.5
10	Osage-Hominy	"Miss. lime"	9-23- 8	1	15	21	23	24	27	29	30	32	37	38	40	41	43	37.2	0.16	1.3	18.0	18.4
11	Pawhuska	"Miss. lime" (55 ft. below top of lime)	25, 36-26- 9	1	14	18	21	25	29	32	33	33	39	38	42	42	44	34.8	0.18	1.4	24.6	20.0
	Foraker	"Miss. lime"	16-28- 8	1	10	18	21	25	28	32	34	36	40	40	43	43	42	36.0	0.13	1.2	23.6	19.8
12	Skiatook	Burg. sd.-"Miss. lime" zone	12-22-12	2	—	26½	29	32½	33	33½	31½	31	35	34½	37½	38½	38½	32.5	0.16	1.7	28.3	20.4
13	West Avant	Burg. sd.-"Miss. lime" zone	23-23-10	1	—	—	—	27	31	35	37	38	43	42	44	45	46	27.7	0.24	2.4	40.2	19.8

Hominy pool in T. 23 N., R. 8 E. The oil pool (11) in Secs. 25 and 36, T. 26 N., R. 9 E., is exceptional in that there the oil-bearing bed lies 55 feet below the top of the "Mississippi lime"

A possible third northeastwardly trending belt of country containing oil pools lies about 10 miles northwest of the belt including Pawhuska and embraces the Pearson Junction and Foraker pools in Ts. 27 and 28 N., R. 8 E., and a few other pools, including the isolated wells in Ts. 25 and 26 N., R. 6 E. There the oil is present in the uppermost weathered zone of the "Mississippi lime."

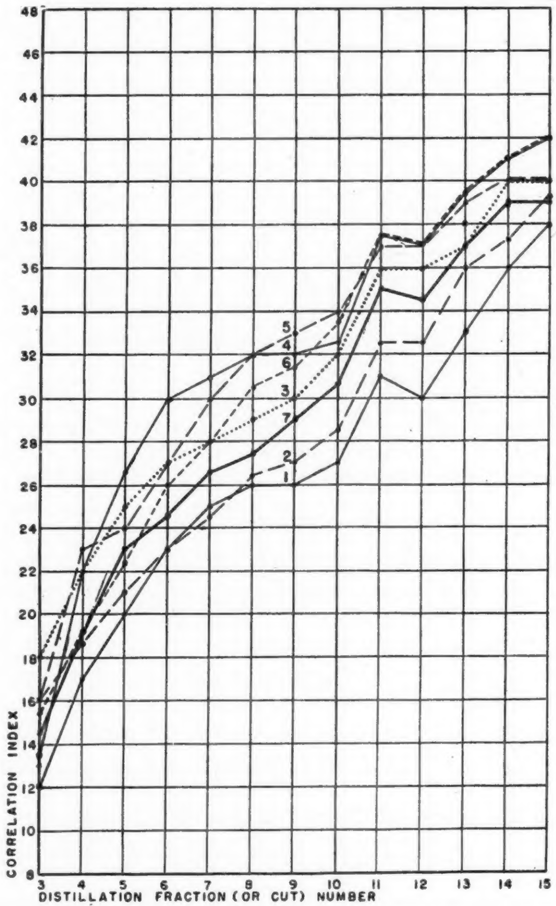


FIG. 11.—Curves showing correlation-index numbers of crude oil classes 1 to 7 in "Mississippi lime" and Burgess sand in Osage and Tulsa counties, Oklahoma. Numbers on curves indicate the classes. (See Table IV for detailed data and classes.)

Everywhere in this region, the Cherokee shale unconformably overlies the "Mississippi lime" and different beds in the Cherokee are in contact with the limestone in different places. In general, the oldest Cherokee beds are present in the southeastern part of the area and progressively younger beds in the Cherokee overlap the "Mississippi lime" northwestward (Fig. 16). Doubtless the relationship is really not so simple as that, however, for the character of the lower Cherokee beds suggests that deposition of sediments in early Cherokee time was quite variable and was accompanied by many fluctuations of the position of the shoreline of the Pennsylvanian sea.

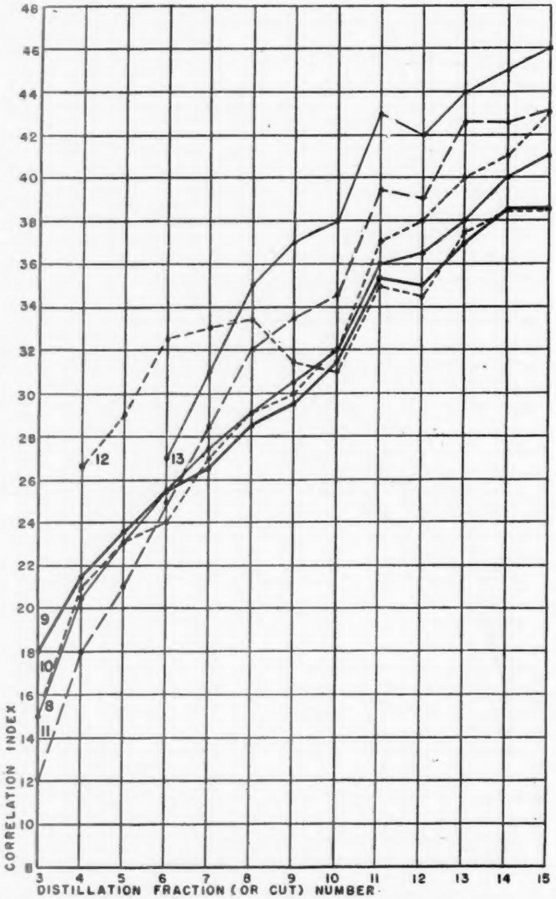


FIG. 12.—Curves showing correlation-index numbers of crude oil classes 8 to 12 in "Mississippi lime" and Burgess sand in Osage and Tulsa counties, Oklahoma. Numbers on curves indicate classes. (See Table IV for detailed data and classes.)

Most pools in the "Mississippi lime," the Burgess sand, and the Burgess sand -"Mississippi lime" zone lie on the crests of small domes and anticlines that are characterized by gentle dips. Notable exceptions include the region near the Domes pool in T. 27 N., Rs. 10 and 11 E., where oil occurs in small pools low on the flanks of broad domes and anticlines. On the other hand, many domes and anticlines in eastern Osage County and adjacent parts of other counties contain no commercially valuable pools of oil in this zone. Much salt water is associated with the oil of essentially all pools, and considerable water is yielded with the oil.

OIL POOLS IN BARTLESVILLE SAND

The total area in Osage County producing oil and gas from the Bartlesville sand is much greater than that of any other oil-bearing bed. Forty-seven samples of oil from 33 pools in the Bartlesville sand in southeastern Osage County, and one sample from one pool that crosses the Osage-Tulsa County boundary (Fig. 13), were analyzed for this investigation. Many factors determined by the analyses, including the correlation indexes for fractions 3 to 15, are shown by classes in Table V, and the average correlation indexes for five of the classes are shown graphically in Figure 14. Six classes of oil are present in the 34 pools. It appears unlikely that many additional classes of oil are present in the Bartlesville sand, for about two-thirds of the pools in this sand in the area are represented by the analyses. It is noteworthy that so few classes of oil are present in the Bartlesville sand inasmuch as in this region the Hominy sand and Arbuckle limestone zone, and the Burgess sand and "Mississippi lime" zone each yield many classes of oil. Moreover, it is pointed out in the following discussion that at least three of the six classes of oil really occur in sand lenses that are at three stratigraphic positions and it is possible that each class of oil occurs in a sand lens that is not really equivalent to any one of the others.

Class 1 oil is represented by analyses of 30 samples from 16 pools, distributed through an area 30 miles long and about 12 miles wide, extending from the Almeda pool in Sec. 19, T. 26 N., R. 12 E., southwestward to the East Hominy pool in Sec. 16, T. 22 N., R. 9 E. It is not unlikely that the area of class 1 oil pools is really more extensive than indicated, for samples were not available from pools northeast and east of the Almeda pool and from pools southwest of the East Hominy pool. The smoothness of the curve for class 1 oil (Fig. 14) shows that this oil has a more uniform change in composition than the oils of the other classes. In general, the oil of class 1 is more naphthenic than oils of classes 2 and 6 and less naphthenic than the oils of classes 3 and 4.

The oils of the Almeda, Pershing, Bulldog, Tidal-Osage, and North Manion pools are essentially alike, and as a group differ slightly from the other oils of class 1 although the differences were deemed not great enough to justify the segregation of these oils in a separate class. It is noteworthy, however, that these 5 pools lie in a northeastward-trending belt of country on the northwestern margin of the area containing the Bartlesville sand.

Class 2 oil is represented by analyses of six samples from five pools near the

southern margin of Osage County and a single sample from a pool that crosses the Osage-Tulsa County line. The area containing the pools is about 25 miles long and trends northwestwardly; it has an unknown width because analyses of samples were unavailable for pools lying southwest of these six pools. The oil of class 2 is

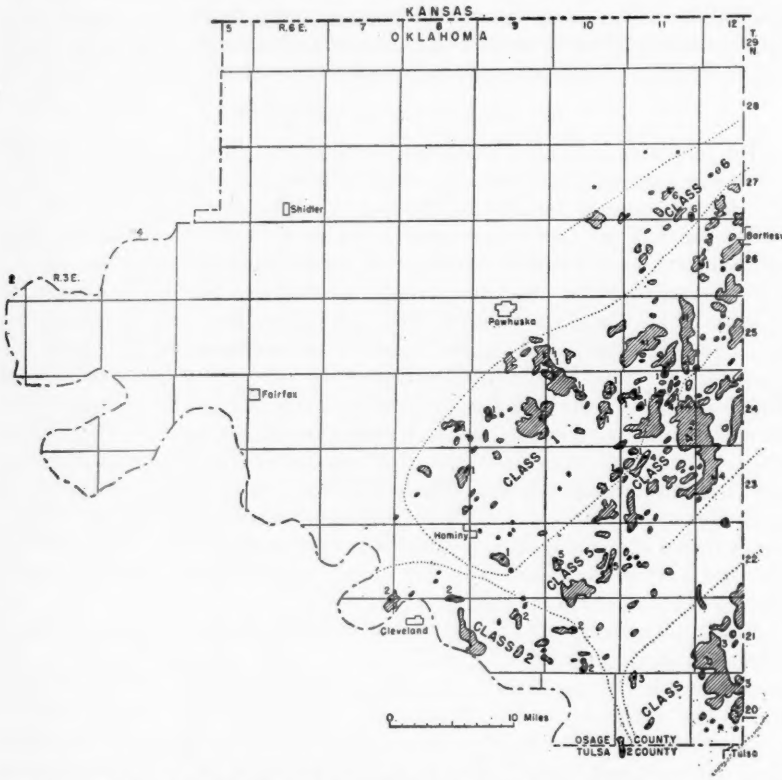


FIG. 13.—Map of Osage County, Oklahoma (after *U. S. Geol. Survey Bull. 900*), showing oil pools and classes of oil in Bartlesville sand. Numbers beside pools indicate classes of oil shown in Table V.

more paraffinic in fractions 6 to 15 than the oil of class 1. The analyses of the oils from the several pools vary slightly, the most noteworthy variation from the average being in the percentage of sulphur in the oil of the Boston pool; the percentage of sulphur is 0.22 of 1 per cent in several of the pools and is only 0.15 and 0.16 of 1 per cent in the two samples from the Boston pool.

Class 3 oil is represented by analyses of five samples from three pools in the southeasternmost part of Osage County. The extent of the class 3 type of oil

TABLE V

CORRELATION-INDEX NUMBERS AND OTHER FACTORS OF ANALYSES OF CRUDE OILS FROM BARTLESVILLE SAND FOR 33 POOLS IN OSAGE COUNTY AND ONE POOL IN TULSA COUNTY, OKLAHOMA

Class of Oil	Pool Name	Oil-Bearing Beds	Location Secs. T. R.	Number of Analyses	Distillation at Atmospheric Pressure								Vacuum Distillation at 40 Millimeters					Crude Oil			Residuum	
			Fraction (or Cut) Number		3	4	5	6	7	8	9	10	11	12	13	14	15					
			Distillation Temperature °C.		75°–100°	100°–125°	125°–150°	150°–175°	175°–200°	200°–225°	225°–250°	250°–275°	Up to 200°	200°–225°	225°–250°	250°–275°	275°–300°	A.P.I. Gravity of Crude	Sulphur Content of Crude, Per Cent	Carbon Residue of Crude, Per Cent	Residuum, Per Cent	A.P.I. Gravity of Residuum
1	Almeda	Bartlesville	19-26-12	1	16	20	23	25	27	28	30	32	36	36	38	40	41	34.8	0.18	1.5	26.3	19.0
	Woolaroc	Bartlesville	11, 36-25-11	2	16½	20	22	24½	26½	29	31	33	38	38	41½	42	43½	35.3	0.18	1.5	25.0	19.0
	Quapaw	Bartlesville	20-25-11	1	14	22	24	26	28	30	32	34	39	40	42	44	44	31.7	0.18	1.8	30.9	19.8
	South Quapaw	Bartlesville	3-24-11, 34-25-11	2	17½	20½	22½	24½	27	29½	31½	33	37½	38½	41½	43	44	36.3	0.15	1.2	23.3	19.2
	Barnsdall	Bartlesville	8, 10, 17, 18-24-11	5	17½	20½	23	25½	27½	30	31½	33½	37½	38	40½	42½	43½	35.4	0.16	1.2	23.0	19.4
	South Barnsdall	Bartlesville	6-23-11, 12-23-10	2	17½	21½	24½	27½	30	31½	31	32	37½	37½	40	42	43	34.8	0.18	1.4	24.2	19.1
	West Barnsdall	Bartlesville	1, 12, 23-24-10	3	16	20	23	26	28½	30	31½	33	38	38½	41½	42½	43½	38.2	0.16	1.0	20.9	19.9
	Avant (northwest end)	Bartlesville	11-24-11	1	18	21	24	26	29	31	32	34	38	37	40	42	43	35.4	0.16	1.6	25.3	19.7
	Pershing	Bartlesville	6, 9, 10-24-10, 24, 36-25- 9	5	18½	20	22	25	27½	29½	31	32½	36½	36	39½	40	41½	37.8	0.15	1.0	20.4	19.8
	Bulldog	Bartlesville	20-24- 9	2	17½	20	22½	25½	27	29½	31	32½	37	36½	39½	41	42½	35.6	0.16	1.3	22.7	19.1
	Wynona	Bartlesville	24-24- 9	1	23	21	23	26	27	31	32	34	39	39	41	43	45	34.0	0.18	1.6	24.4	18.5
	Tidal-Osage	Barltesville	25-24- 8	2	13½	21	24	26	28½	31	31	33½	36½	36	37	40	42	38.5	0.16	1.2	20.4	19.5
	North Manion	Bartlesville	13-23- 8	2	15	19½	22½	25	27	29	30½	32	35	35	37	38½	39	38.9	0.13	0.9	19.5	20.3
	East Hominy	Bartlesville	16-22- 9	1	16	20	22	25	27	29	31	32	37	37	40	41	42	36.6	0.16	1.3	23.5	20.3
2	Shell Creek	Bartlesville	5-19-11	1	16	19	21	22	24	24	26	27	33	32	35	37	39	39.6	0.22	1.5	20.5	18.4
	Prue	Bartlesville	33-21-10	1	19	22	25	26	27	28	28	29	32	34	36	38	40	37.4	0.24	1.7	22.2	19.0
	Madalene	Bartlesville	16-21-10	1	18	21	22	23	25	27	27	29	33	33	36	38	40	38.0	0.22	1.4	21.0	18.6
	East Osage City	Bartlesville	10-21- 9	1	18	22	23	24	25	27	27	29	35	36	38	40	40	38.0	0.24	1.4	19.6	17.9
	Osage City	Bartlesville	2-21- 8	1	16	19	20	23	24	24	26	28	34	33	36	38	39	39.0	0.22	1.2	20.0	19.0
	Boston	Bartlesville	1-21- 7	2	19	19½	21½	23	24½	27½	28½	29½	33½	34	37	39	40	37.8	0.16	1.3	20.6	19.4
3	Turley	Lower Bartlesville	15-20-12	1	27	30	31	32	34	34	32	31	33	33	36	38	41	32.8	0.23	1.7	27.5	19.4
	Flat Rock	Lower Bartlesville	3-20-12	1	36	33	32	35	36	37	35	32	35	34	37	38	40	31.7	0.23	1.7	28.2	19.5
	Flat Rock	Lower Bartlesville	21-21-12	1	28	30	31	32	33	34	32	31	34	35	37	39	40	32.8	0.22	1.7	26.7	19.2
	Pioneer	Lower Bartlesville	5-20-11	2	36	35	36	38½	38½	37½	34	32	34	33	35½	38	39	31.9	0.25	1.8	26.9	18.6
4	Avant	Bartlesville	17-23-12	1	24	27	30	32	33	33	32	32	37	37	40	41	43	33.8	0.19	1.9	24.6	18.6
	Avant	Bartlesville	24-24-11	1	19	23	27	30	32	33	32	33	40	41	43	45	45	34.8	0.18	1.4	23.0	19.0
	Avant	Bartlesville	14-24-11	1	—	27	29	32	33	33	32	33	37	37	40	42	43	31.1	0.20	1.5	28.1	19.4
	Avant	Bartlesville	15-24-11	1	20	24	27	30	32	33	33	34	38	39	41	43	45	33.6	0.16	1.3	23.5	19.4
	Barnsdall	Bartlesville	16-24-11	1	—	25	27	29	31	32	33	33	38	38	40	41	42	32.7	0.19	1.3	26.4	20.0
	South Barnsdall	Bartlesville	5-23-11	1	23	25	29	32	33	33	32	33	38	38	42	42	43	34.8	0.18	1.4	24.3	19.4
5	East Wildhorse	Bartlesville	23-22-10	1	17	24	25	26	27	27	28	30	35	35	37	40	41	34.6	0.23	1.6	22.5	18.6
	North Wildhorse	Bartlesville	18-22-10	1	15	26	27	27	28	28	29	31	37	36	38	40	40	35.0	0.18	1.4	24.8	20.2
6	Backius	Upper Bartlesville	36-27-11	1	15	18	20	22	23	25	28	29	35	34	37	38	39	34.2	0.18	1.6	26.4	19.5
	Bighorse	Upper Bartlesville	22-27-11	1	—	17	19	21	23	24	28	29	35	34	36	38	39	35.8	0.18	1.6	26.5	19.4

northeast and southwest from the few pools shown in Figure 13 is unknown because analyses of the oils from pools in these areas are unavailable. The oil is distinctly more naphthenic in fractions 3 to 9 and probably contains more aromatic hydrocarbons than the oils of classes 1, 2, 4, 5, and 6. The curve showing

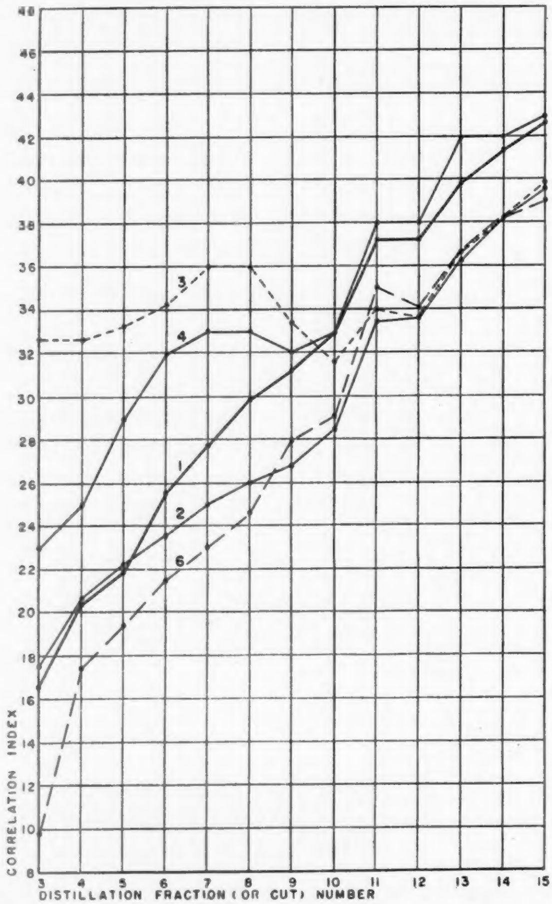


FIG. 14.—Curves showing correlation-index numbers of crude-oil classes 1 to 4 and 6 in Bartlesville sand in Osage County, Oklahoma. Numbers on curves indicate classes. (See Table V for detailed data and classes.)

the correlation indexes is the flattest of the curves for all six classes. The average A.P.I. gravity of the class 3 oil is lowest and the percentage of sulphur and residuum is the greatest of all the classes. The character of class 3 oil makes it particularly valuable for the manufacture of high anti-knock gasoline.

Class 4 oil is represented by analyses of six samples from three oil pools, including the large Avant pool in Ts. 23 and 24 N., Rs. 11 and 12 E. The extent of the area containing class 4 oil, particularly northeastward from the Avant pool, is unknown because analyses of the oil from many pools in that area are unavailable. The character of the oil as expressed by the curve of the correlation indexes is nearest the class 3 oil; nevertheless, the class 4 oil is less naphthenic in fractions 3 to 9 and more naphthenic in fractions 10 to 15 than the class 3 oil.

Class 5 oil is represented by only two samples from two pools in T. 22 N., R. 10 E. The extent of the area containing class 5 oil is unknown. The curve of the correlation indexes of the oil (not shown in Fig. 14) indicates that the oil is more naphthenic in fractions 3 to 6 than class 1 oil and slightly more paraffinic in fractions 8 to 15.

Class 6 oil is represented by analyses of two samples from two pools in T. 27 N., R. 11 E. This oil is on the whole more paraffinic than any of the other five classes.

The Bartlesville sand occurs as elongate lenses, 10 feet to greater than 100 feet thick, in the lower part of the Cherokee shale. The distribution of the oil pools in the Bartlesville sand is controlled by the extent of the reservoir sand bodies rather than by the attitude of the beds.[6] The sand was deposited as a series of offshore bars along the northwestern margin of the Pennsylvanian sea as its shoreline fluctuated to and fro over a relatively narrow belt of country trending northeastward across northeastern Oklahoma and southeastern Kansas.[7] The interval between the sand and the base of the Cherokee decreases northwestward from about 200 feet at the southeast corner of Osage County to zero along a northeastward-trending course that passes about 3 miles southeast of Pawhuska. At this latter locality the sand overlaps the "Mississippi lime" and pinches out. This condition is illustrated in cross section in Figure 16. Most of the sand bodies are elongate northeastward and are aligned in roughly parallel northeastward-trending belts. Many of the sand bodies are within a strip of country about 20 miles wide, whose northwest margin is about 3 miles southeast of Pawhuska and whose northeast end lies outside Osage County. Bordering this strip on the southeast is a second strip 6 to 8 miles wide that contains scarcely no large sand bodies. A third strip, lying adjacent on the southeast and extending beyond the boundaries of Osage County, contains broad thick sand lenses.[8]

[6] N. W. Bass, "Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma," *U. S. Geol. Survey Bull, 900-K* (1942), p. 382.

[7] N. W. Bass, Constance Leatherock, W. R. Dillard, and L. E. Kennedy, "Origin and Distribution of Bartlesville and Burbank Shoestring Oil Sands in Parts of Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1 (January, 1937), pp. 55–56.
A. W. McCoy, "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (1921), pp. 559–61.

[8] N. W. Bass, "Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma," Part XI, "Summary of Subsurface Geology with Special Reference to Oil and Gas," *U.S. Geol. Survey Bull. 900-K* (1942), p. 363.

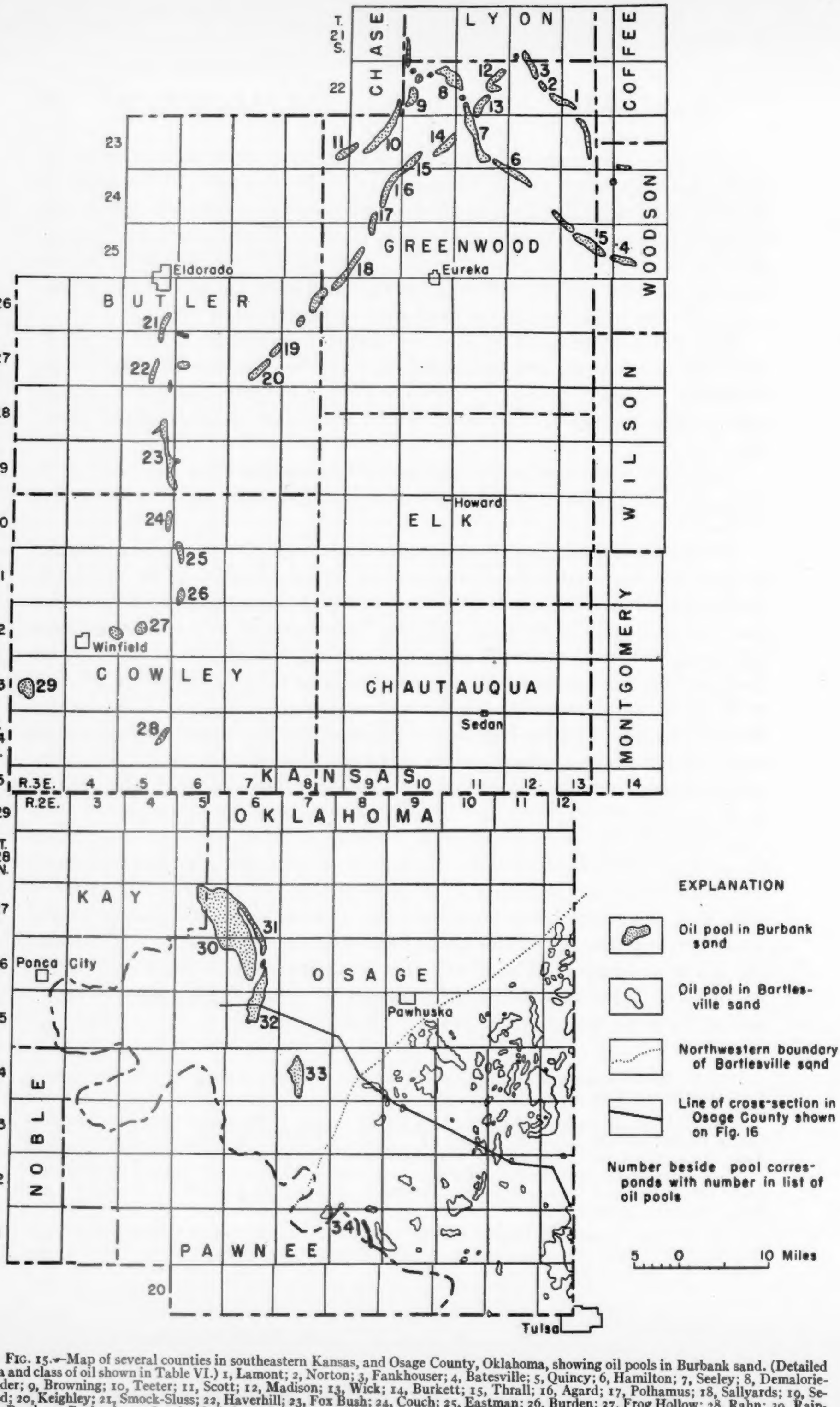


FIG. 15.—Map of several counties in southeastern Kansas, and Osage County, Oklahoma, showing oil pools in Burbank sand. (Detailed data and class of oil shown in Table VI.) 1, Lamont; 2, Norton; 3, Fankhouser; 4, Batesville; 5, Quincy; 6, Hamilton; 7, Seeley; 8, Demalorie-Souder; 9, Browning; 10, Teeter; 11, Scott; 12, Madison; 13, Wick; 14, Burkett; 15, Thrall; 16, Agard; 17, Polhamus; 18, Sallyards; 19, Seward; 20, Keighley; 21, Smock-Sluss; 22, Haverhill; 23, Fox Bush; 24, Couch; 25, Eastman; 26, Burden; 27, Frog Hollow; 28, Rahn; 29, Rainbow Bend; 30, Burbank; 31, Stanley Stringer of Burbank 32, South Burbank; 33, Naval Reserve; 34, Osage City.

The belts of Bartlesville sand lenses are of slightly different age, though they lie within a stratigraphic zone about 250 feet thick. The sand lenses near the southeast corner of Osage County containing class 3 oil are definitely lower stratigraphically and, therefore, older than the lenses of the belt of country passing through Hominy and Bartlesville that contain class 1 oil. An examination of the well logs shows that the class 6 oil is contained in very thin sand lenses that are distinctly higher stratigraphically and, therefore, younger than the sand lenses containing the class 1 oil. Moreover, it is almost a certainty that the individual minor belts of sand lenses within the 20-mile-wide strip of country passing through Hominy and Bartlesville are of slightly different age; in general, they are progressively younger northwestward across the area. There the sand lenses are so intricately interfingered, however, that they can not be separated in the well logs. The sand lenses near the northwestern edge of the belt, including those of the Almeda, Pershing, Bulldog, Tidal-Osage, and North Manion pools, likely are of slightly different age from the other sand lenses of the belt. The large thick sand body of the Avant pool containing class 4 oil may interfinger with the sand bodies of the Barnsdall field lying west of it, but the details of their relationship are unknown. Class 4 oil is present in the SE. ¼ of Sec. 15 and the SE. ¼ of Sec. 16, T. 24 N., R. 11 E., and class 1 oil is present in the SW. ¼ of Sec. 10 and the SW. ¼ of Sec. 11, T. 24 N., R. 11 E. These facts suggest that a prong of the Avant sand body may extend westward across the south part of Secs. 14, 15, and 16, and probably Secs. 21 to 23, T. 24 N., R. 11 E.

The southern part of Osage County including the area containing the class 2 oil is characterized by many Bartlesville sand pools on the crests of domes and anticlines; the sand commonly contains water on the flanks of the structures.[9] It is impossible to correlate precisely the oil-bearing sands shown in the logs of the several pools of class 2 oil because they are several miles apart.

The two pools containing the class 5 oil are in an area intervening between the area characterized by sand lens pools lacking structural control and the area wherein the oil pools appear to be controlled by the structure of the rocks. One of the pools of class 5 oil is on the North Wildhorse dome and the other lies low on the west flank of a large anticline.[10]

OIL POOLS IN BURBANK SAND

Eighty samples of oil from 33 pools in the Burbank sand in Woodson, Lyon, Greenwood, Butler, and Cowley counties, Kansas, and Osage County, Oklahoma, were analyzed for this investigation. The pools are distributed through an area 150 miles long and from 1 to 35 miles wide (Fig. 15). Many factors deter-

[9] N. W. Bass, *op cit.*, p. 383.

[10] N. W. Bass, L. E. Kennedy, W. R. Dillard, Otto Leatherock, and J. H. Hengst, "Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma," *U. S. Geol. Survey Bull. 900-A* (1938), Pl. 1.

TABLE VI

CORRELATION-INDEX NUMBERS AND OTHER FACTORS OF ANALYSES OF CRUDE OILS FROM BURBANK SAND FOR 33 POOLS IN WOODSON, LYON, GREENWOOD, BUTLER, AND COWLEY COUNTIES, KANSAS, AND OSAGE COUNTY, OKLAHOMA

			Distillation at Atmospheric Pressure								Vacuum Distillation at 40 Millimeters					Crude Oil			Residuum	
	Fraction (or Cut) Number		3	4	5	6	7	8	9	10	11	12	13	14	15					
Pool Name	Distillation Temperature °C. Location Secs. T. R.	Number of Analyses	75°–100°	100°–125°	125°–150°	150°–175°	175°–200°	200°–225°	225°–250°	250°–275°	Up to 200°	200°–225°	225°–250°	250°–275°	275°–300°	A.P.I. Gravity of Crude	Sulphur Content of Crude, Per Cent	Carbon Residue of Crude, Per Cent	Residuum, Per Cent	A.P.I. Gravity of Residuum
Lamont	25-22S-12E Kans.	2	14½	18	19	20½	23½	26	27	29	33	34½	37½	39½	41½	38.4	0.19	1.9	22.3	17.5
	29-22S-13E Kans.																			
Norton	22-22S-12E Kans.	1	17	19	21	24	26	27	28	30	34	35	37	39	42	41.5	0.18	1.7	19.9	17.8
Fankhouser	32-21S-12E Kans.																			
	4-22S-12E Kans.	2	16	17½	20½	23	25	26	28½	30	34	34	37½	39½	42½	39.9	0.19	1.7	19.4	17.6
Batesville	19, 28, 29-25S-14E Kans.	3	16½	18½	20	23	24½	26½	28	29	33½	34	36½	38½	40½	35.8	0.19	1.9	21.3	17.9
Quincy	8, 10, 23-25S-13E Kans.	3	16½	19½	21½	26½	25½	27½	28½	30	33	33½	37½	38	41½	36.2	0.20	1.4	19.3	18.1
Hamilton	8, 16-24S-12E Kans.																			
	36-23S-11E Kans.	4	16½	19	21½	23	23½	26½	28	29½	33	33	36	37½	40	38.9	0.19	1.5	21.0	18.6
Seeley	16-23S-11E Kans.																			
	32-22S-11E Kans.	2	16	19	21	23	25½	27	28½	30	33½	34	36	37	39½	40.4	0.19	1.5	20.4	18.9
Demalorie-Souder	11, 13-22S-10E Kans.	2	17½	20	21½	23	25	26	27	29	32½	33½	36	37½	40	41.1	0.18	1.5	19.5	18.7
Browning	20, 29-22S-10E Kans.	2	15	19	19½	22½	24½	25	26½	29	32½	32½	35½	36½	38½	41.6	0.18	1.2	19.7	19.6
Teeter	2, 15-23S-9E Kans.	2	16	19	21	23	24½	26	27½	30	33	34	37	37½	40	40.0	0.19	1.3	19.8	19.3
Scott	25-23S-8E Kans.																			
	19-23S-9E Kans.	2	16½	19	21	23½	25	26½	28	30	33	34	36½	37½	39½	39.8	0.19	1.4	21.5	19.0
Madison	11, 23-22S-11E Kans.	2	16½	19	21	23	25	26½	28	29½	33½	34	37½	38½	42	39.6	0.20	1.6	20.5	17.9
Wick	27-22S-11E Kans.	1	16	19	21	23	26	26	28	30	34	34	37	38	41	41.1	0.19	1.6	20.3	18.4
Burkett	23, 24-23S-10E Kans.	2	16	18½	21	23	24½	26½	27½	29½	33	34	36½	37½	39	38.3	0.21	2.0	22.6	18.0
Thrall	28, 32-23S-10E Kans.	2	16	18	20	22½	24	26	28	29½	33	33½	36	37½	39	39.7	0.19	1.9	21.7	19.3
Agard	1, 23-24S-9E Kans.	2	15½	18½	19½	22½	23	26	27	29	33	33½	36½	37½	39½	39.8	0.21	1.9	20.0	18.3
Polhamus	34-24S-9E Kans.																			
	4-25S-9E Kans.	2	16	18½	19½	23	24½	26	27½	28½	33	33	36	38	39	39.9	0.20	1.7	21.4	18.5
Sallyards	19-25S-9E Kans.																			
	2-26S-8E Kans.	2	14½	18	19½	23	25	26½	27	29½	33½	34	37	39	41	39.5	0.21	1.8	21.4	18.0
Seward	13-27S-7E Kans.	1	18	20	22	23	25	27	28	30	33	34	37	39	41	39.4	0.19	1.4	19.0	18.6
Keighley	22, 27-27S-7E Kans.	2	17	19½	21	23½	25	26	28	29½	32½	33	37	38½	41	40.8	0.20	1.3	18.8	18.9
Smock-Sluss	26-26S-5E Kans.																			
	2-27S-5E Kans.	2	16	19	21	22½	24	26½	28½	29	34	35	37½	39½	41	39.3	0.24	2.0	22.3	17.5
Haverhill	22, 27-27S-5E Kans.	2	17	20	21	23	25	26½	28	29	33	33½	36½	38	39½	39.5	0.21	1.3	19.9	18.9
Fox Bush	26-28S-5E Kans.																			
	12, 24-29S-5E Kans.	3	16½	18½	20	22½	23½	26	26½	29	33	33½	36½	37½	39	39.4	0.19	1.3	19.5	19.2
Couch	13-30S-5E Kans.	2	17½	19	20½	22½	24½	26	27½	29	33½	33	36½	37	39	41.1	0.17	1.3	19.6	19.4
Eastman	31-30S-6E Kans.																			
	6-31S-6E Kans.	2	17	19	21	22	24	25½	27	29	32½	33	36½	37	39	38.2	0.18	1.4	21.9	19.3
Burden	30, 31-31S-6E Kans.	2	17	18	19½	22½	23½	25½	26½	28	31½	32½	36	37½	38	38.6	0.19	1.5	20.9	19.0
Frog Hollow	16, 21-32S-5E Kans.	2	16½	19	21	23	23½	26	27	29	33½	33	36½	38	40½	43.1	—	—	16.5	19.4
Rahn	13-34S-5E Kans.	1	14	17	18	21	23	25	27	29	32	32	35	37	39	39.4	—	—	26.4	20.3
Rainbow Bend	20, 21, 28-33S-3E Kans.	3	16	19	20½	23	24	25½	27	29	32½	33½	36½	37½	40½	40.9	—	—	18.3	19.0
Burbank	23, 24-27N-5E Okla.																			
	17, 19, 28, 29-27N-6E Okla.																			
	4, 9-26N-6E Okla.	9	17	19½	21	22½	24½	26	27½	28½	32	32½	35½	36	38	38.1	0.18	1.2	24.6	21.3
Stanley Stringer	2, 3-26N-6E Okla.																			
of Burbank	17, 34-27N-6E Okla.	4	15½	19	20½	22	23	25	27	28	32	33	36	36½	38	38.8	0.18	1.2	23.7	20.9
South Burbank	14, 26, 34-26N-6E Okla.	4	17	19	21	23	24	26	28	28	32	33	35	36	38	38.7	0.18	1.2	24.3	21.3
Naval Reserve	21-24N-7E Okla.	1	17	20	21	23	24	25	27	28	33	33	35	37	37	38.2	0.20	1.4	25.5	21.3
*Osage City	23-21N-8E Okla.	2	16	19	20½	23	23½	24½	26	27½	33	33½	36½	37½	39½	39.0	0.20	1.4	20.7	19.1

* Red Fork sand, equivalent to Burbank sand.

mined by the analyses, including the correlation indexes for fractions 3 to 15, are shown in Table VI; the average correlation indexes for the Burbank and South Burbank pools are shown graphically in Figure 22, and such indexes for 16 samples in the Haverhill trend of southern Kansas are shown graphically in Figure 20. The oils from all pools are contained in one class. As was pointed out in an earlier paper,[11] "The series of index numbers of 80 analyses from Kansas and Oklahoma are remarkably uniform. The slight variations that occur, with the exception to be noted, are probably within the limits of experimental error of the analyses. The uniformity of the index numbers indicates that the crude oil from these 33 pools is similar in composition."

The only deviation from the uniformity shown by the correlation indexes and percentages for the various crude oils is found in those from the Burbank, South Burbank, and Naval Reserve pools in Oklahoma, "which have a slightly greater quantity of residuum with a slightly higher A.P.I. gravity than the Kansas oils. This difference in the residuum is also indicated by the slightly lower index numbers for fractions 13, 14, and 15 of these oils than for the corresponding fractions of the Kansas oils."

The analyses of the oils from the Couch, Eastman, and Fox Bush pools in Cowley and Butler counties, Kansas, furnish data on the change in the character of oil that probably takes place by production from a pool. It is well known that the gravity of the oil in a producing pool commonly becomes slightly lower over a period of years. Production of oil began in the Fox Bush pool in 1917, in the Eastman pool in 1924, and in the Couch pool only a few months before the samples of oil were collected for analysis from all three pools near the end of 1940. The data given in Table VI show that except for the A.P.I. gravity of the oil all factors of the analyses tabulated are closely similar for all three pools. The A.P.I. gravity of the oil from the Couch pool is 1.7° higher than that of the oil from the Fox Bush pool and 2.9° higher than that of the oil from the Eastman pool. An examination of the quantities distilled off in the first few fractions, the data for which are not shown in Table VI, reveals that a greater quantity of these lighter-gravity fractions is present in the oil from the Couch pool than in the oils from the other two pools. For example, the total per cent contained in the first three fractions is 10.6 for the oil from the Couch pool, 7.9 for the oil from the Fox Bush pool, and 6.4 for the oil from the Eastman pool. Inasmuch as the oils from these three pools appear to be so similar in all respects except the A.P.I. gravity and the amounts of the fractions, it appears reasonable to conclude that some of the highly volatile hydrocarbons contained originally in the oil were dissipated during the 16 and 23 years that the Eastman and Fox Bush pools have been yielding oil. It is noteworthy that the close agreement of the correlation indexes for the oils from the three pools shows that the commercial produc-

[11] L. M. Neumann, N. W. Bass, R. L. Ginter, S. F. Mauney, T. F. Newman, Charles Ryniker, and H. M. Smith, "Relationship of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), pp. 1806–07.

tion of oil from two of the pools for many years has not altered the character of the oil.

The Burbank sand occurs as lenses in the Cherokee shale, 50 feet more or less stratigraphically above the position of the Bartlesville sand. Like the Bartlesville sand, the Burbank was deposited as a chain of offshore bars along the western shore of the Pennsylvanian sea,[12] when, at a later date than that of Bartlesville sand deposition, the shoreline had migrated many miles westward. The Burbank sand lenses are commonly 50 to 100 feet thick, ½ to 1½ miles wide, and 1 to 7 miles long, excepting the lens of the Burbank field which is 4 miles wide and 11 miles long. Except for small offsets the lenses are arranged approximately end to

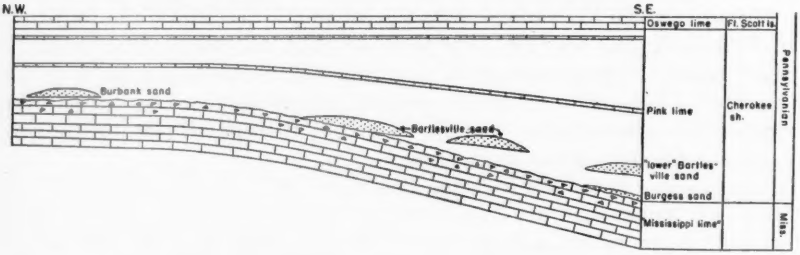


FIG. 16.—Cross section northwestward across Osage County, Oklahoma, showing Cherokee shale and adjacent formations and relationship of Bartlesville and Burbank sands to top of "Mississippi lime." Section is aligned on top of "Oswego lime." Line of cross section shown on Figure 15.

end in systems called trends. These are the well known "shoestring sands." Two principal systems or trends are present in Kansas about 10 miles apart. The sand bodies of both trends lie within a thin stratigraphic zone and it is only where the two trends cross that they can be differentiated in the well logs. The two trends apparently represent deposition during two stages of the sea that were separated by a relatively short time.[13] The Burbank sand lies at depths ranging from about 1,400 feet in Woodson County, Kansas, to 3,000 feet in western Osage County, Oklahoma.

OIL POOLS IN ZONES YOUNGER THAN BURBANK SAND

Of the many oil pools in the region in sands that are younger than the Burbank sand, samples of oil were analyzed from pools in only seven zones in Osage County, Oklahoma, and in four zones in Cowley County, Kansas. The zones in Oklahoma are in ascending order, the Squirrel (Prue) sand, "Big lime" (Oologah limestone), and the Cleveland, Jones, Wayside, Peoples, and Okesa

[12] N. W. Bass, Constance Leatherock, W. R. Dillard, and L. E. Kennedy, "Origin and Distribution of Bartlesville and Burbank Shoestring Sands in Parts of Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1 (January, 1937), pp. 55–65.

[13] N. W. Bass, "Origin of the Shoestring Sands of Greenwood and Butler counties, Kansas," *Kansas Geol. Survey Bull. 23* (1936), pp. 106–11.

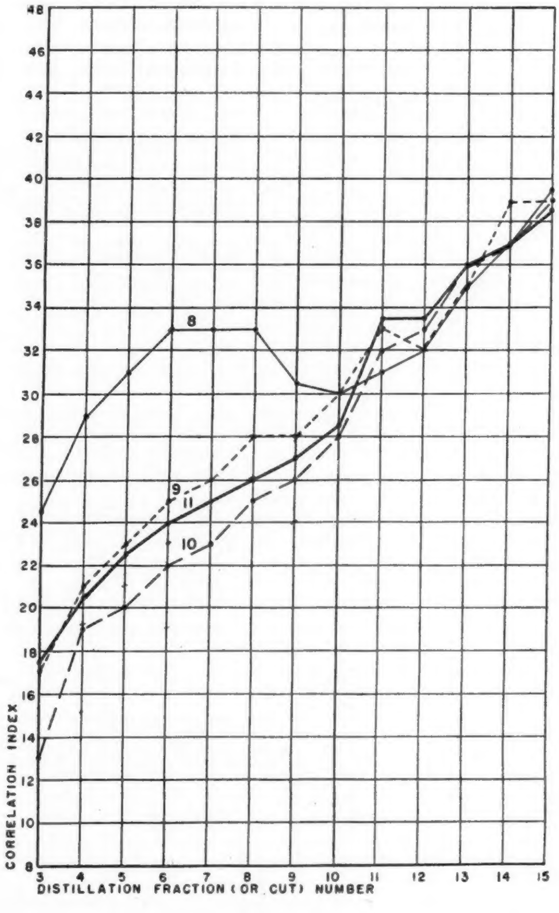


FIG. 17.—Curves showing correlation-index numbers of crude-oil classes 8 to 11 in Squirrel (Prue) sand in Osage County, Oklahoma. Numbers on curves indicate classes. (See Table VII for detailed data and classes.)

(Buzzard) sands, and in Kansas the Rock sand, a sand near the top of the Kansas City group, a zone in the Lansing group, and a sand in the lower part of the Shawnee group. Four of the pools in Oklahoma are in the Squirrel (Prue) sand, and two pools are in each of the zones, the "Big lime," Jones sand, and Peoples sand; in Kansas, three pools are in the Kansas City group. The other sands in Oklahoma and Kansas are represented by one pool each. Many factors determined by the analyses, including the correlation indexes for fractions 3 to 15,

TABLE VII

CORRELATION-INDEX NUMBERS AND OTHER FACTORS OF ANALYSES OF CRUDE OILS FROM 7 ZONES YOUNGER THAN BURBANK SAND FOR 13 POOLS IN OSAGE COUNTY, OKLAHOMA, AND 4 ZONES FOR 5 POOLS IN COWLEY COUNTY, KANSAS

			Fraction (or Cut) Number		Distillation at Atmospheric Pressure								Vacuum Distillation at 40 Millimeters					Crude Oil			Residuum	
					3	4	5	6	7	8	9	10	11	12	13	14	15					
Class of Oil	Pool Name	Oil-Bearing Beds	Distillation Temperature °C. Location Secs. T. R.	Number of Analyses	75°–100°	100°–125°	125°–150°	150°–175°	175°–200°	200°–225°	225°–250°	250°–275°	Up to 200°	200°–225°	225°–250°	250°–275°	275°–300°	A.P.I. Gravity of Crude	Sulphur Content of Crude, Per Cent	Carbon Residue of Crude, Per Cent	Residuum, Per Cent	A.P.I. Gravity of Residuum
			Oklahoma																			
1	Osage City	Okesa (Buzzard) sand	30-21- 9 30-22- 9	3	16½	18	17½	18½	20½	22½	23	24½	31½	32	34½	36½	38	39.8	0.22	1.4	21.7	19.4
2	Big Bend	Peoples (Layton of Burbank) sand	20-25- 3	1	16	19	21	23	25	26	28	30	33	32	35	37	38	40.9	0.12	1.4	20.1	19.7
3	Osage City	Peoples sand	23, 24-21- 8	2	15	18½	21	23	23½	24½	25½	26½	32	32½	34½	37	38	41.2	0.20	1.3	20.4	19.5
	Birch Creek	Jones sand	28-24-10	2	15½	19	20½	23	24	25½	26	28	33½	33	35	37	39	38.6	0.17	1.7	24.8	19.2
	West Avant	Jones sand	28-23-11	1	16	20	22	23	24	25	26	28	32	32	35	36	38	38.2	0.20	1.6	25.7	19.8
4	South Hickory	Wayside	3, 10-28-11	2	15½	19½	22	23½	24½	27½	29	30½	35½	35½	38½	39½	42½	37.1	0.20	2.2	26.4	18.0
5	Wildhorse	Cleveland	33, 34, 35-22-10	3	—	35	35½	38½	39½	39½	37½	35	36	35½	37	37½	40	31.4	0.25	2.0	27.6	18.9
6	West Avant	"Big lime"	5-22-11	1	—	35	36	37	37	38	39	39	41	40	41	40	41	30.6	0.23	2.0	30.7	19.7
7	Flat Rock	"Big lime"	4-20-12	1	15	18	18	20	21	23	25	27	30	30	33	37	37	36.8	0.16	1.5	28.5	20.0
8	East Madalene	Squirrel (Prue) sand	23-21-10	2	24½	29	31	33	33	33	30½	30	31	32	35	37	39½	35.6	0.22	1.6	25.1	19.7
9	Prue	Squirrel (Prue) sand	33-21-10	1	17	21	23	25	26	28	28	30	33	32	35	39	39	37.4	0.22	1.5	23.0	18.6
10	Dalton	Squirrel (Prue) sand	7-24- 8	1	13	19	20	22	23	25	26	28	32	33	36	37	39	36.2	0.18	1.3	28.4	21.1
11	Olson	Squirrel (Prue) sand	13, 24-26- 4	2	17½	20½	22½	24	25	26	27	28½	33½	33½	36	37	38½	41.5	0.11	0.7	13.3	21.0
			Kansas																			
12	Winfield	Shawnee (1400 foot sand)	19-32- 5	1	7	15	17	19	21	24	24	26	34	34	36	38	40	38.4	0.23	1.9	22.1	18.1
13	Graham	Lansing	9-33- 3	1	7½	13	15	18	21	24	26	28	37	37	40	43	45	40.6	0.1	0.9	12.6	17.1
14	Hittle	Kansas City	21-31- 4	1	19	22	23	26	28	28	30	32	34	34	37	40	43	39.4	0.22	1.7	18.5	17.1
15	Graham	Kansas City	9-33- 3	1	8	15	17	20	22	23	24	25	33	33	35	37	39	38.6	0.12	2.1	24.0	17.8
16	Slick-Carson	Kansas City	19-32- 3	1	10	17	20	22	23	24	27	29	34	33	37	39	42	38.8	0.1	2.1	21.9	16.8
17	Rock	Rock sand	15, 21-30- 4	2	18	20½	23	25	28	29½	31	32½	37	38	41½	43½	46	39.1	0.18	2.1	16.8	14.8

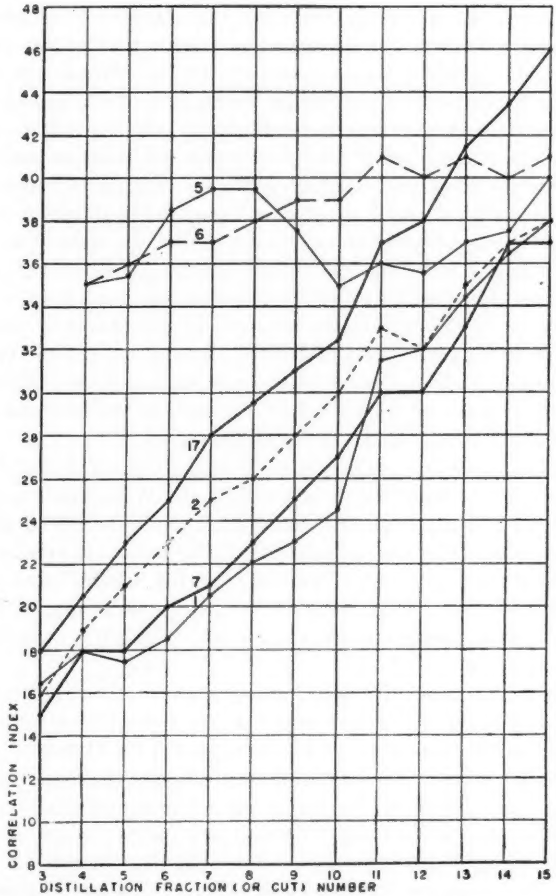


FIG. 18.—Curves showing correlation-index numbers of crude-oil classes 1, 2, 5 to 7, and 17 in sands younger than Burbank sand in Osage County, Oklahoma, and Cowley County, Kansas. (See Table VII for detailed data and classes.)

are shown in Table VII. The correlation indexes for the pools in the Squirrel (Prue) sand are shown graphically in Figure 17; and such indexes for the oils in the other zones are shown in Figures 18 to 21, 29, and 30. Each pool contains a separate class of oil except for classes 3 and 4, each of which contains two pools. Several of the oils vary from each other by only a slight amount, however. For example, classes 11, 3, 2, 12, and 10 cannot be distinguished by the properties of fractions 11 to 15 inclusive, but they exhibit slightly greater naphthenicity in the order named. The stratigraphic interval between the Jones and Peoples

sand is not great; it is noteworthy, therefore, that similar oils are present in the two sands (class 3) because the investigation reveals that in this area the oils from different stratigraphic zones commonly are of different character. The curves showing the correlation indexes for the Squirrel (Prue) sand in the Olson pool (Fig. 17) and the Peoples sand in the Big Bend pool (Fig. 18) are not greatly different from the average curve for the oil from the Burbank sand (Fig. 22).

The oil from the Rock pool of Cowley County, Kansas, is compared graphically in Figure 20 with the oil of the Burbank sand in the Haverhill trend, which passes through Cowley County about 7 miles east of the Rock pool. The crude oil of the Rock pool is more naphthenic throughout all fractions than the crude oil from the Burbank sand.[14] The reservoir bed of the Rock pool is a sand lens not more than 50 feet higher stratigraphically in the Cherokee shale than the Burbank sand. In contrast, the oil from the Lansing zone of the Graham pool is distinctly more paraffinic in the first 10 fractions and more naphthenic in the last 5 fractions than the oil from the Burbank sand in the Rainbow Bend pool, which is only about 2 miles south of the Graham pool.

The correlation-index curves for the oil from the Cleveland sand in the Wildhorse pool and for oil from the "Big lime" in the West Avant pool (Fig. 18) show that these two oils are not only much more naphthenic than all the others but that they undoubtedly contain aromatic hydrocarbons in greater abundance than most other oils in the region. The oil from the Squirrel sand in the East Madalene pool (Fig. 17) also is strongly naphthenic and aromatic. The oil from the Okesa sand in two pools in the Osage City field (Fig. 18) is the most paraffinic oil of all oils analyzed in this region.

In Oklahoma, the seven oil-bearing zones, younger than the Burbank sand, are distributed through a sequence about 1,300 feet thick extending from the upper part of the Cherokee shale to the upper part of the Ochelata formation of the Pennsylvanian system. The stratigraphic position of the zones is shown in the columnar section of Figure 3. Depths to the oil-bearing zones range from 310 feet to the Okesa sand in the Osage City field to 3,100 feet to the Squirrel (Prue) sand in the Olson pool. All zones except the "Big lime" consist of fine-grained quartz sand. The sands are lenticular and contain oil or gas in a relatively few small areas. The beds of sand in each of the zones are undoubtedly of slightly different age from place to place. For example, each of the four pools in the Squirrel (Prue) sand has a separate class of oil. The name Squirrel (Prue), however, is applied to all sands that lie at various positions from a few feet to 75 feet below the top of the Cherokee shale. The beds of sand are characteristically lenticular, and are likely of slightly different age in each pool.

The stratigraphic position of the four oil-bearing zones in Cowley County, Kansas, is shown in the columnar section in Figure 23. The oil-bearing beds in the Shawnee, Lansing, and Kansas City groups are sands or limy sands in

[14] L. M. Neumann, N. W. Bass, R. L. Ginter, S. F. Mauney, T. F. Newman, Charles Ryniker, and H. M. Smith, *op. cit.*, p. 1807.

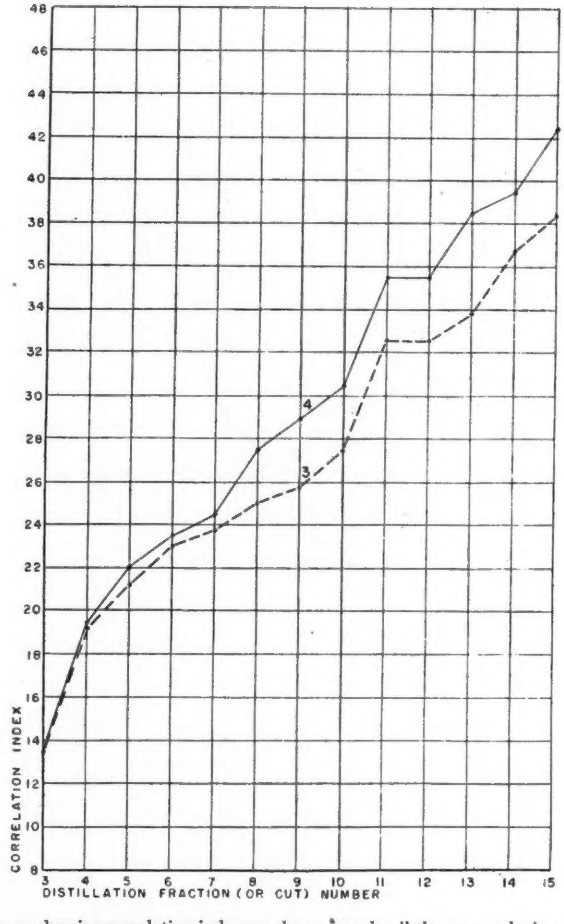


FIG. 19.—Curves showing correlation-index numbers of crude-oil classes 3 and 4 in sands younger than Burbank sand in Osage County, Oklahoma. (See Table VII for detailed data and classes.)

formations that consist dominantly of limestone a few miles north of Cowley County.

OIL POOLS IN BARTLESVILLE SAND AND "MISSISSIPPI LIME" NEAR WHERE THE TWO ZONES ARE IN CONTACT

Many of the larger oil pools in the uppermost weathered chert beds of the "Mississippi lime" in Osage County, Oklahoma, are in a belt about 15 miles wide, extending northeastwardly from T. 23 N., R. 8 E., to a few miles west of the northeast corner of the county (Fig. 10). On the southeast, this belt of coun-

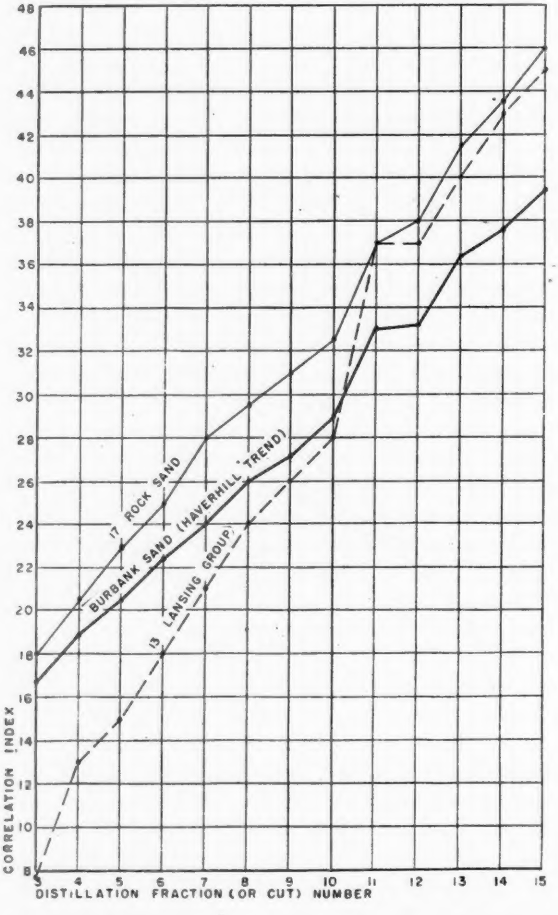


FIG. 20.—Curves showing correlation-index numbers of crude-oil classes 13 and 17 in sands younger than Burbank sand in Cowley County, Kansas, and curve of oil (average of 16 analyses) in Burbank sand in Haverhill trend in Butler and Cowley counties, Kansas. (See Tables VII and VI for detailed data and classes.)

try lies adjacent to and merges with a broad belt of country that contains many oil pools in the Bartlesville sand (Fig. 13). Along the common margins of the two belts the Bartlesville sand rests on the old erosion surface on the "Mississippi lime" and in some pools oil occurs in both the sand and the limestone. The Bartlesville sand is absent northwest of this marginal belt. Except for some minor differences, the oil of the "Mississippi lime" pools all along this belt is similar

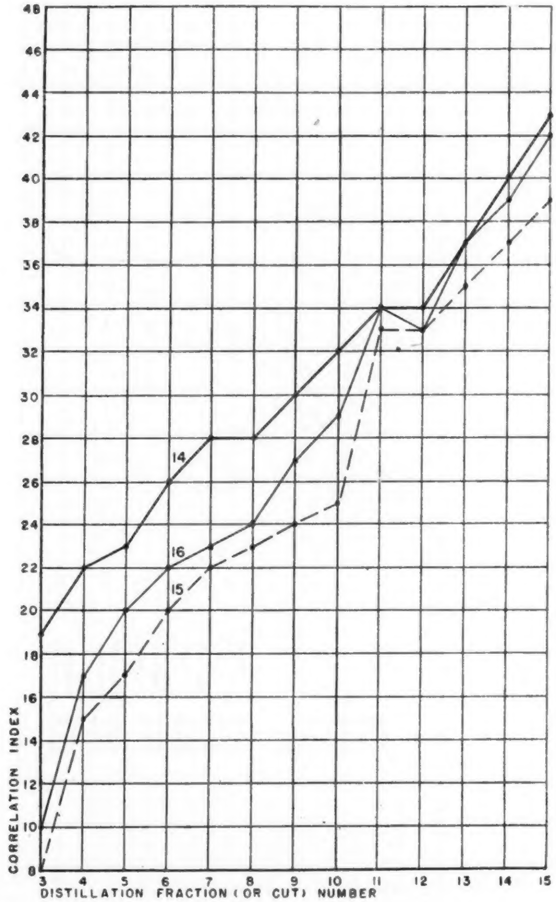


FIG. 21.—Curves showing correlation-index numbers of crude-oil classes 14 to 16 in a sand (so-called Layton sand of Kansas) near top of Kansas City group in Hittle, Slick-Carson, and Graham pools in Cowley County, Kansas. (See Table VII for detailed data and classes.)

to the oil in the Bartlesville sand in the broad belt on the southeast. Moreover, in the part of the belt southwest of Pawhuska the oils in the two zones are essentially alike. There the overlap of the Bartlesville sand on the "Mississippi lime" is positively known from the records of scores of wells. The northwest margin of the sand passes northeastward through the northwestern part of T. 23 N., R. 8 E., and continues northeastward, passing 2 to 3 miles southeast of Pawhuska. The Atlantic pool in the southwestern part of T. 25 N., R. 8 E. (Fig. 10) and the New England pool in Sec. 30, T. 25 N., R. 9 E., both of which are in the

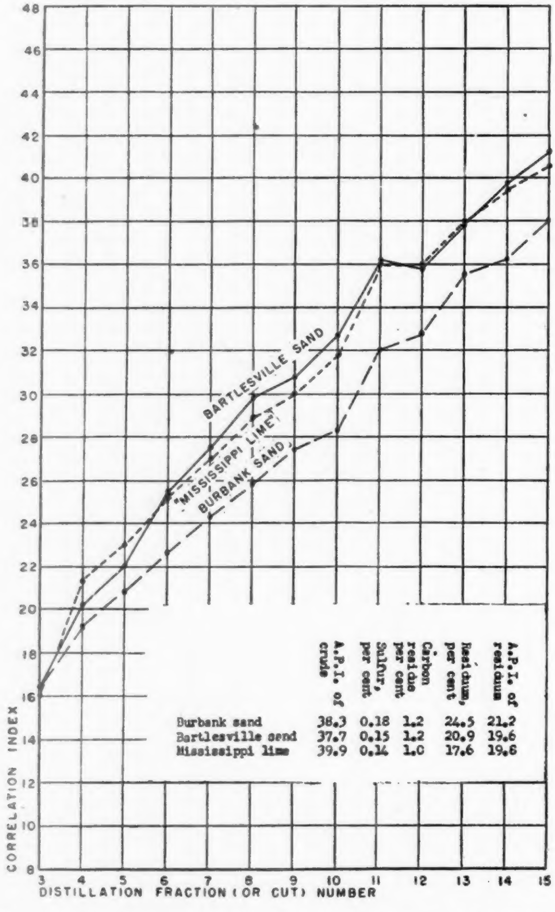


FIG. 22.—Curves showing correlation-index numbers of an average of 6 analyses of crude oil from Bartlesville sand (2 analyses from each, Bulldog pool in Sec. 20, T. 24 N., R. 8 E., Tidal-Osage pool in Sec. 25, T. 24 N., R. 8 E., and the North Manion pool in Sec. 13, T. 23 N., R. 8 E., shown in Table V), and an average of 5 analyses of crude oil from "Mississippi lime" pools (in Secs. 15, 22, T. 24 N., R. 8 E., Sec. 30, T. 25 N., R. 8 E., Sec. 19, T. 25 N., R. 9 E., and Sec. 9, T. 23 N., R. 8 E. shown in Table IV), and an average of 17 analyses of crude oil from Burbank sand in Burbank and South Burbank fields.

"Mississippi lime," lie northwest of the margin of the Bartlesville sand. On the other hand, the Bulldog pool in Sec. 20, T. 24 N., R. 9 E. (Fig. 13), the eastern part of the Tidal-Osage pool in Secs. 25 and 26, T. 24 N., R. 8 E., and the North Manion pool in Secs. 13 and 24, T. 23 N., R. 8 E., all in the Bartlesville sand, lie southeast of the margin. The average correlation indexes for 6 samples of oil

from the Bartlesville sand (2 samples from each of the foregoing 3 pools) and the average of such indexes for 6 samples from 5 pools in the "Mississippi lime" and 17 samples from the Burbank and South Burbank pools, are shown graphically and the average for certain other factors of the analyses are tabulated in Figure 22. These data illustrate the close similarity of the oils from the Bartles-

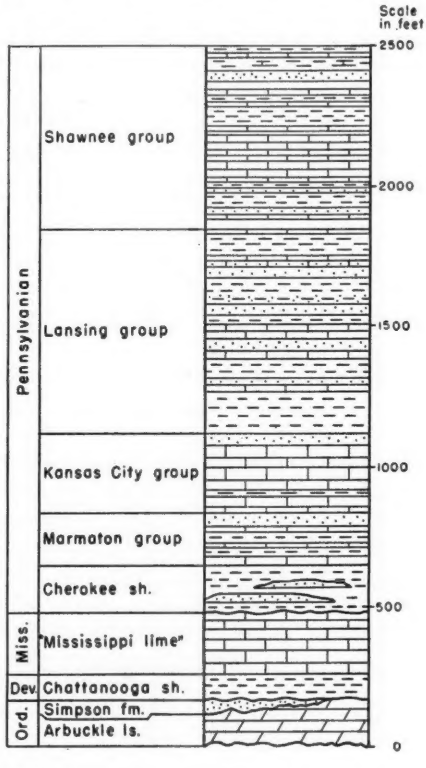


FIG. 23.—Generalized columnar section of a part of the rocks in Cowley County, Kansas (after *Kansas Geol. Survey Bull. 12*).

ville sand and "Mississippi lime" and their dissimilarity to the oil from the Burbank sand.

OIL POOLS IN MORE THAN ONE ZONE IN THE SAME FIELD

Samples of oil from zones lying at different stratigraphic positions in the same field were analyzed for a few fields in this region to obtain data on the character of the oils in the several zones, which in turn might suggest whether oil has migrated from one zone to another. In the Flat Rock field in Secs. 3, 4, 8, and 9,

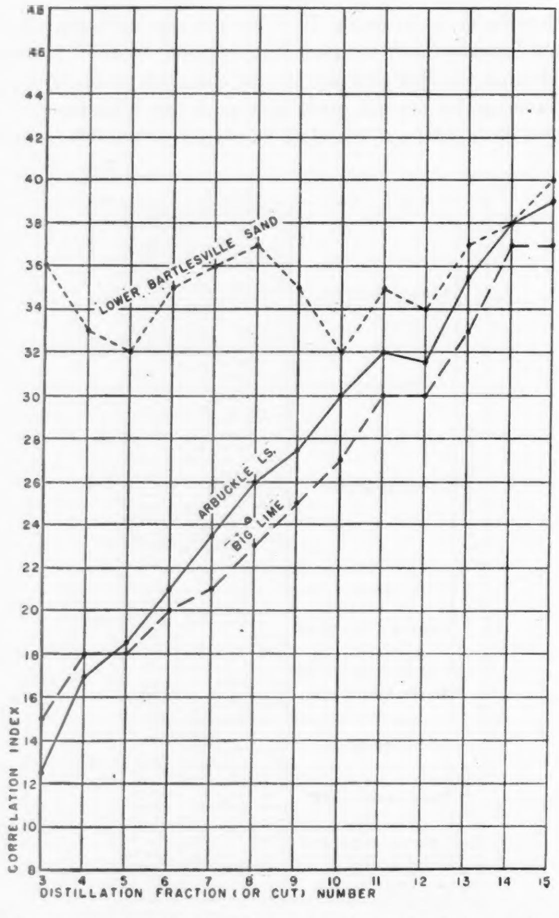


FIG. 24.—Curves showing correlation-index numbers for crude oils from Arbuckle limestone or Hominy sand (class 12, Table II), the "Big lime" (class 7, Table VII, and Fig. 18), and lower Bartlesville sand [class 3 (Sec. 3, T. 20 N., R. 12 E.) Table V], in Flat Rock field, T. 20 N., R. 12 E., Osage County, Oklahoma.

T. 20 N., R. 12 E., southeastern Osage County, Oklahoma, samples of oil were obtained from the "Big lime" and Bartlesville (lower) sand, both of which are in the Pennsylvanian system, and from the Arbuckle limestone or Hominy sand zone of the Ordovician system. The stratigraphic interval between the "Big lime" and Bartlesville sand is about 600 feet and between the Bartlesville sand and Arbuckle limestone or Hominy sand zone is about 550 feet. The curves of the correlation indexes for the oils from the three zones are shown in Figure

24. The curve for each oil is different from the other two. The oil from the Big lime is more paraffinic than the oil from the Arbuckle limestone and Hominy sand, and the oil from the Bartlesville (lower) sand is much more naphthenic and aromatic than the other two oils. The A.P.I. gravity, percentage of sulphur, and percentage of residuum of the three oils vary widely (Tables II, VII, and V).

The Wildhorse field in T. 22 N., R. 10 E., Osage County, Oklahoma, yields oil from the Cleveland and Bartlesville sands, both of Pennsylvanian age, and the Arbuckle limestone. Samples of oil from the Cleveland sand and Arbuckle limestone were analyzed. The stratigraphic interval between the two zones is about 1,300 feet. The curves of the correlation indexes are shown in Figure 25. The two oils are greatly dissimilar in the correlation indexes, A.P.I. gravity, percentage of sulphur, percentage of carbon residue of the crude, and the percentage of residuum (Tables II and VII).

The principal oil pool in the East Hominy field in T. 22 N., R. 9 E., Osage County, Oklahoma, is in the Bartlesville sand and one well yielded oil for a time from the Arbuckle limestone. The stratigraphic interval between the two zones is about 500 feet. Analyses of the oils from the two zones show that the oil from the Bartlesville sand is distinctly less naphthenic than oil from the Arbuckle limestone (Fig. 26). The oil from the Bartlesville sand has a higher A.P.I. gravity and a smaller percentage of residuum than the oil from the Arbuckle limestone (Tables II and V).

Samples of oil from the Kansas City group of the Pennsylvanian system and the Arbuckle limestone in the Hittle field (Fig. 7) in T. 31 S., R. 4 E., Cowley County, Kansas, were analyzed and, like the fields just described, the analyses show that the two zones contain different classes of oil. The difference in the oils from the two zones in the Hittle field is shown chiefly by the curves of the correlation indexes shown in Figure 27. The oil from the Kansas City group is more naphthenic in the first seven fractions and less naphthenic in the last eight fractions than the oil from the Arbuckle limestone.

In the Graham field in Sec. 9, T. 33 S., R. 3 E., Cowley County, Kansas, the curves of the correlation indexes and other factors revealed by the analyses are different for each oil from three zones, the Lansing and Kansas City groups, both of Pennsylvanian age, and the Arbuckle limestone (Fig. 28).

In the Slick-Carson field in Sec. 19, T. 32 S., R. 3 E., Cowley County, Kansas, oil from the Arbuckle limestone is more naphthenic than the oil from the Kansas City group (Fig. 29). Of the oil pools in several zones in the Winfield field, analyses of oil samples from the Arbuckle limestone and the "1,400-foot" sand, which lies in the lower part of the Shawnee group, are available. The graph in Figure 30 shows that the oil in the Arbuckle limestone is more naphthenic than the oil in the "1,400-foot" sand.

Other fields in the region yield different classes of oil in oil-bearing zones occurring at several stratigraphic positions. The conclusion is apparent that in most oil fields in this region different classes of oil occur at different stratigraphic

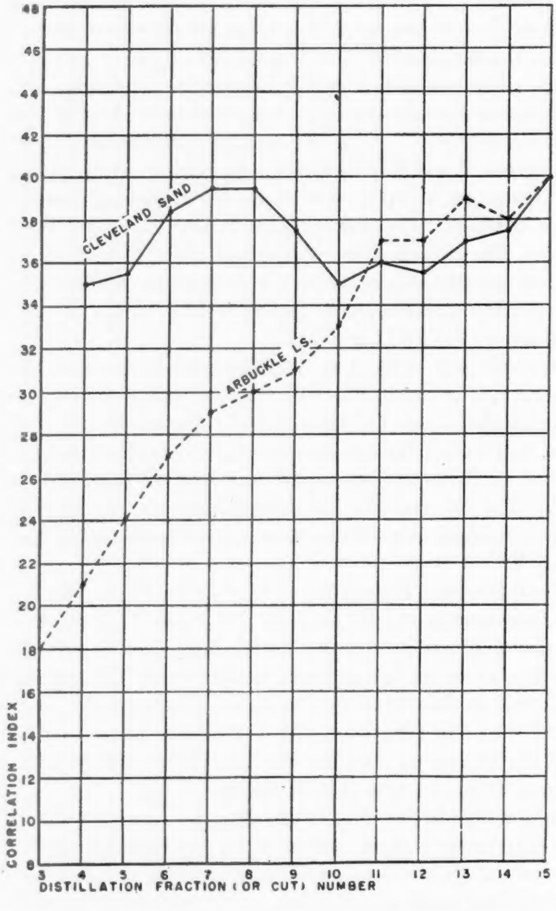


FIG. 25.—Curves showing correlation-index numbers for crude oils from Arbuckle limestone (class 7, Table II) and Cleveland sand (class 5, Table VII, and Fig. 18) in Wildhorse field, Osage County, Oklahoma.

positions, which fact suggests that migration of oil from one zone to another has not occurred. Important exceptions to this condition are present in several fields in Oklahoma and Kansas, however, for some fields contain strikingly similar oils in several stratigraphic zones. The general subject of oils in several zones in oil fields will be described in a paper to be published later.

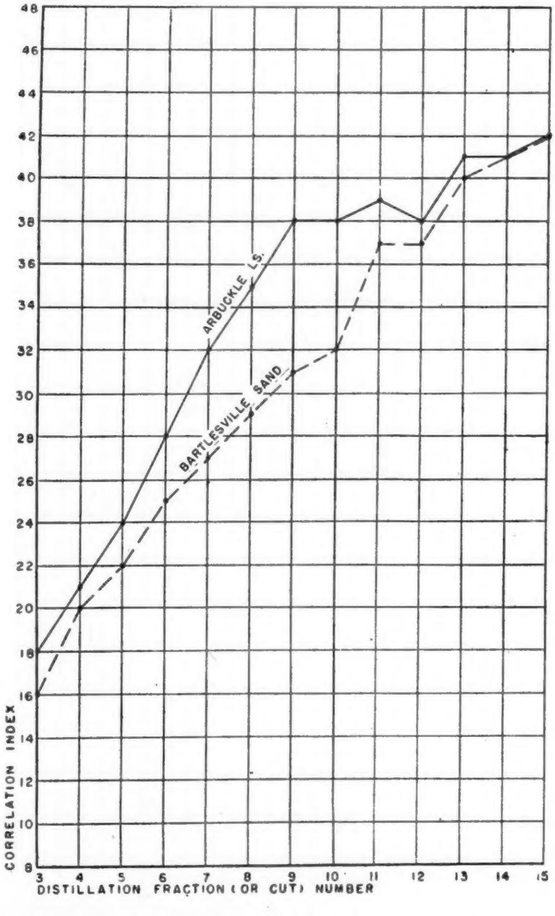


FIG. 26.—Curves showing correlation-index numbers for crude oils from Arbuckle limestone (class 16, Table II, and Fig. 6) and Bartlesville sand (class 1, Table V) in Sec. 16, T. 22 N., R. 9 E., in East Hominy field, Osage County, Oklahoma.

EFFECT OF STRUCTURAL MOVEMENT ON CHARACTER OF OIL

The region containing the oil fields whose oils are described herein is believed to have had a similar structural history throughout. The region is situated on the Prairie Plains monocline, which involves parts of western Missouri, Kansas, and Oklahoma, and adjacent states, wherein the strata dip westward at about 25 to 40 feet to the mile. The monocline is modified locally by low anticlinal

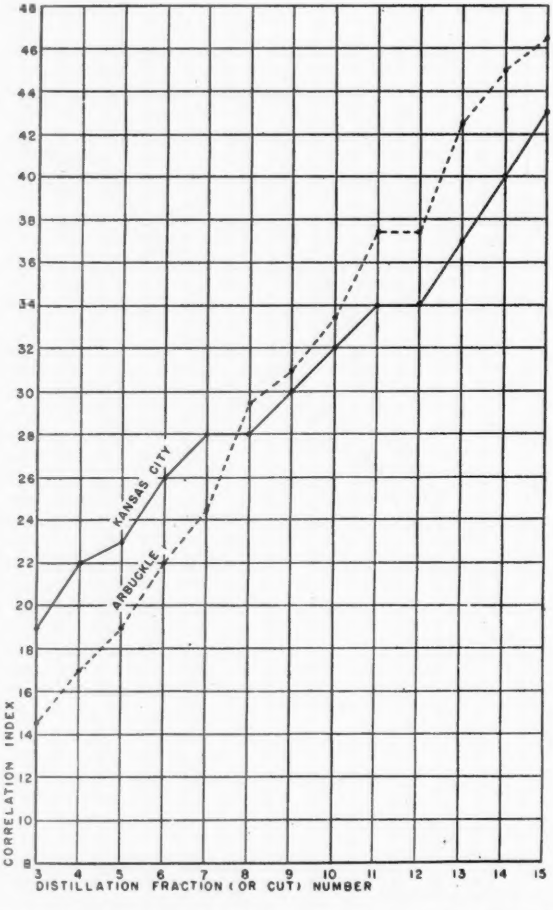


FIG. 27.—Curves showing correlation-index numbers for crude oils from Arbuckle limestone (class 4, Table III, and Fig. 8) and Kansas City group (class 14, Table VII, and Fig. 20) in Hittle field in T. 31 S., R. 4 E., Cowley County, Kansas.

noses, domes, terraces, synclines, and basins of small lateral extent. The rate of dip increases in passing from younger to older rocks and the data indicate that the initial folding occurred in the oldest sedimentary rocks and was rejuvenated many times[15] from Cambrian to post-Permian time. In general, the same types of structural features are present throughout the region containing

[15] A. W. McCoy, "An Interpretation of Local Structural Development in Mid-Continent Areas Associated with Deposits of Petroleum," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), pp. 582–83.

the oil pools whose oils were investigated. Consequently, the narrow belt of country, 150 miles long, containing the oil pools in the Burbank sand should reveal

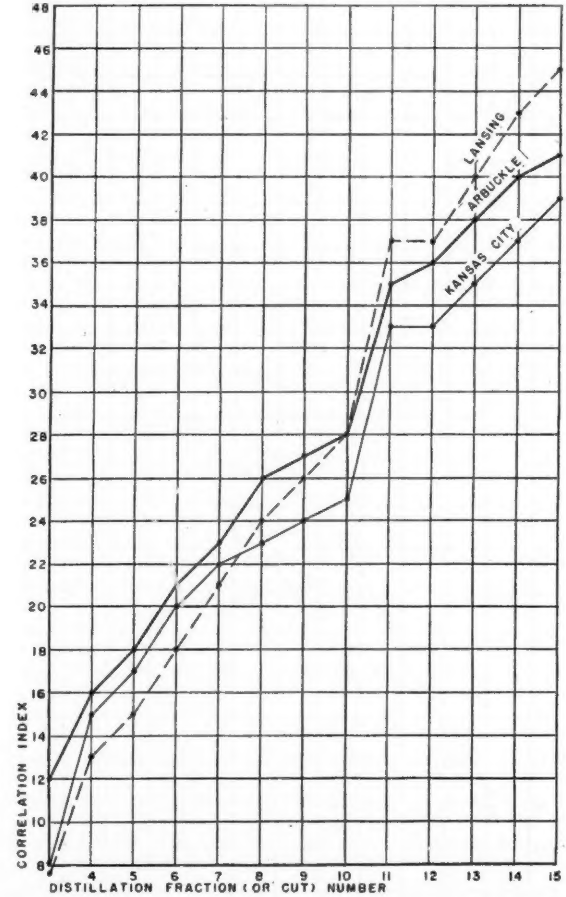


FIG. 28.—Curves showing correlation-index numbers for crude oils from Arbuckle limestone (class 1, Table III, and Fig. 8), Kansas City group (so-called Layton sand of Kansas) (class 15, Table VII, and Fig. 21), and Lansing group (class 13, Table VII, and Fig. 20) in Graham field in Sec. 9, T. 33 S., R. 3 E., Cowley County, Kansas.

whether the local structural movements have influenced the character of the oil. The analyses of oil samples obtained from pools in the Burbank sand situated on various types of structural features show that the oils are all similar. Thus the local structural movements appear not to have altered the oils.

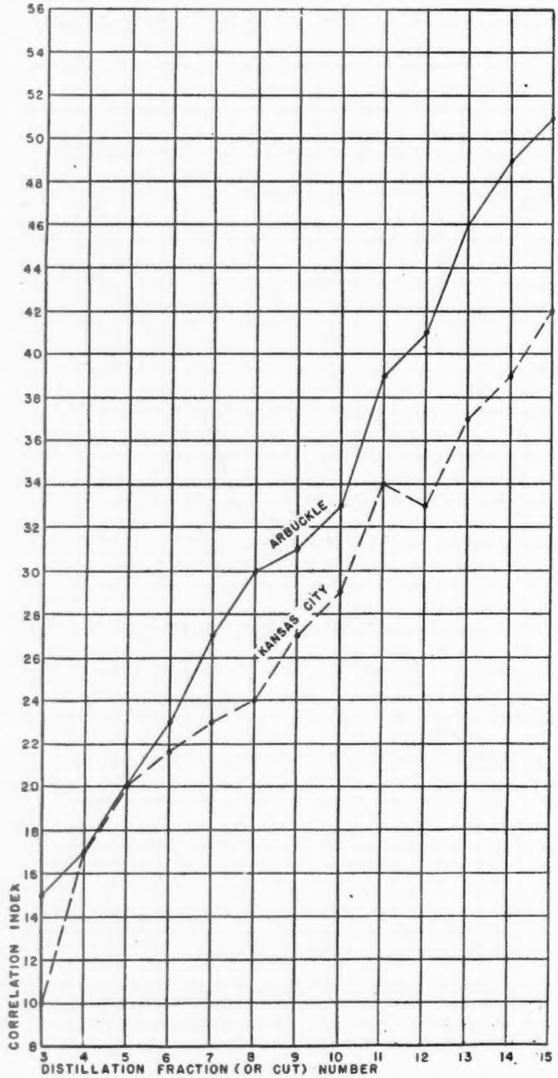


FIG. 29.—Curves showing correlation-index numbers for crude oils from Arbuckle limestone (class 2, Table III, and Fig. 8) and Kansas City group (so-called Layton sand of Kansas) (class 16, Table VII, and Fig. 21) in Slick-Carson field in Sec. 19, T. 32 S., R. 3 E., Cowley County, Kansas.

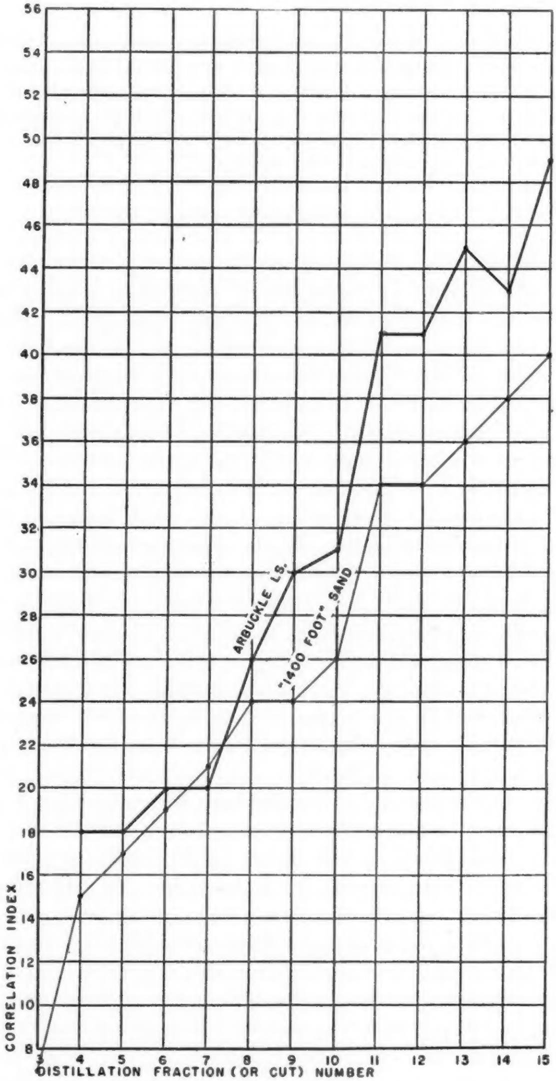


FIG. 30.—Curves showing correlation-index numbers for crude oils from Arbuckle limestone (class 3, Table III, and Fig. 8) and Shawnee group—"1,400-foot" sand (class 12, Table VII) in Winfield field in Sec. 22, T. 32 S., R. 4 E., and Sec. 19, T. 32 S., R. 5 E., Cowley County, Kansas.

As was pointed out previously,[16]

> The tilting movement that formed the Prairie Plains monocline and the recent period of erosion that removed much more overburden in some places than in others likewise have not affected the oil, as the oil pools in Woodson County, Kansas, lie at an altitude of about 350–400 feet below sea-level and a depth of 1,400 feet, and those in southeastern Butler County lie at an altitude of about 1,300 feet below sea-level and a depth of 2,700 feet, and yet the oils from these two localities are similar.

POSSIBLE INTERPRETATIONS

Though geologists are in general agreement that oil is derived from vegetable and animal remains buried in the sediments they are at considerable disagreement and have but scant information on many items concerning the origin, accumulation, and character of oil, among which are: (1) the method and time of formation of oil, (2) the distance the oil may have migrated laterally or vertically and the time of migration to an oil pool, (3) the changes in character the oil may have undergone during the long time since it formed, (4) the effect, if any, on the character of the oil produced by its contact with brines and minerals in the beds containing it or through which it may have migrated, and (5) the effect that deformation and depth of burial may have had upon the character of the oil. The present investigation fails to answer any of these items, but the facts revealed by it afford suggestions toward the solution of some of them in this area. Probably the most noteworthy facts revealed by the investigation are: (1) that the oil pools in several relatively small areas contain a great variety of crude oils, (2) that the greatest variety of oils is present in beds associated with unconformities such as those at the top of the Arbuckle limestone and at the top of the "Mississippi lime," (3) the least varieties of oils occur in beds of a single thin stratigraphic zone, such as the Burbank sand in which a single class of oil is present in 33 pools occupying an area 150 miles long, (4) that different classes of crude oil are present in reservoir beds lying at different stratigraphic horizons in the same or different fields even though the oil-bearing zones are separated by intervals of only 50 feet or less, (5) that where one oil-bearing zone is in contact with another, such as the Bartlesville sand and the "Mississippi lime" in central Osage County, Oklahoma, the oil in the two zones is similar or alike, and (6) the structural movements that formed the many domes, anticlines, synclines, and basins present in the area appear not to have altered the oils.

These facts suggest that the local environment of the source sediments is the chief factor that determined the character of the crude oil of these oil pools. Thus they contribute evidence to the hypothesis that the source of oil is in the thin richly organic sediments in the local area of a given pool[17] rather than being

[16] L. M. Neumann, N. W. Bass, R. L. Ginter, S. F. Mauney, T. F. Newman, Charles Ryniker, and H. M. Smith, "Relationship of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), pp. 1808–09.

[17] A. W. McCoy and W. R. Keyte, "Present Interpretations of the Structural Theory for Oil

sparsely disseminated through the sediments over a broad region and accumulated into pools by migration over long distances.[18]

Probably the most convincing evidence is furnished by the oil pools of the Burbank and Bartlesville sands as contrasted with those in beds associated with the regional unconformities at the tops of the Arbuckle limestone and the "Mississippi lime." As was pointed out previously,[19]

> The similarity in composition of the crude oils from the many pools in the Burbank sand suggests that the oil was derived from sediments whose occurrence is restricted to a relatively narrow belt that extends along the system of sand bodies northwestward from Woodson County to northwestern Greenwood County, Kansas, thence southward to southern Osage County, Oklahoma, and undoubtedly farther south—a total distance of 150 miles or more. While the sand bodies were forming the environment apparently was essentially the same along this narrow belt.

The most likely source material for the oil was the rich organic marsh sediments that accumulated simultaneously and immediately after the deposition of the sand bodies. Some of these sediments interfingered with the sand and the great mass of them formed in the marshes adjacent to the sand bodies and overlaid the sand bodies as the marshes were filled and gradually migrated seaward over the site of the old shoreline.

> The total thickness of the source sediments probably does not greatly exceed the thickness of the sand lenses; certainly where coal is present a few feet above the sand the source beds do not extend as high in the sequence of rocks as the coal beds. Probably the strongest evidence that the source beds have a limited vertical extent is the fact that the Rock sand [Fig. 20, this paper] and the Bartlesville sand [Fig. 22, this paper] contain crude oil that is unlike the oil in the Burbank sand, although both of these sands lie within the Cherokee shale, and are separated by small stratigraphic intervals from the Burbank sand. All three sands are oil-bearing in the same region and, therefore, have been subjected to essentially the same treatment as to depth of burial, and regional structural movements.[20]

The environment during the deposition of the Bartlesville sand is believed to have been similar to that for the deposition of the Burbank sand except that the belts of sand lenses were more intricately overlapped. Moreover, the total interval containing sand lenses called Bartlesville is much greater than the Burbank, and probably really contains several belts of sand lenses lying in several thin stratigraphic zones of slightly different age. There is no doubt but that the Bartlesville sand lenses near Tulsa were deposited long prior to the deposition of the Bartlesville sand lenses near Pawhuska. Thus environmental conditions

and Gas Migration and Accumulation," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), p. 296.
F. R. Clark, "Origin and Accumulation of Oil," *ibid.*, pp. 309, 334.

[18] J. L. Rich, "Problems of the Origin, Migration, and Accumulation of Oil," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), p. 337.

[19] L. M. Neumann, N. W. Bass, R. L. Ginter, S. F. Mauney, T. F. Newman, Charles Ryniker, and H. M. Smith, *op. cit.*, p. 1808.

[20] *Ibid.*, p. 1808.

probably changed several times during so-called Bartlesville time. The general depositional processes during the several stages of sand deposition are believed to have been similar. The Bartlesville sand throughout the great belt of country lying east of Pawhuska, Oklahoma (Fig. 13), and along the northwest margin of the Bartlesville sand, was deposited during the latest stage after the Cherokee sea had encroached farther upon the land and conditions were more stabilized. The similarity of the crude oils (class 1) in the Bartlesville sand in this great belt of country suggests that the environment during the deposition of the sand lenses in this belt remained fairly constant.

Moreover, the occurrence of oil, similar to class 1 oil of the Bartlesville sand in the uppermost weathered beds of the "Mississippi lime" in the belt of country adjacent on the northwest to the margin of the Bartlesville sand suggests that rich organic marsh sediments of Bartlesville time furnished the oil for these "Mississippi lime" pools. In fact, the marshes probably extended landward several miles from the sandy shore and were there in contact with the weathered porous beds at the top of the "Mississippi lime."

Many of the oil-bearing zones younger than the Burbank sand are lenticular sands that probably were deposited in a manner similar to the deposition of the Burbank. It should be expected that the environment was somewhat different at the various times when the beds were deposited, for they are separated by long intervals of time. The fact that each zone contains a separate class of oil in the few pools for which data were obtained is in harmony with the expectations.

Some evidence is available that indicates that environmental conditions during the deposition of the source beds associated with the Arbuckle limestone and Hominy sand zone and the "Mississippi lime" and Burgess sand zone varied greatly from place to place. The great variation in the classes of oil in these older zones is in striking contrast to the few classes of oil in the Bartlesville and Burbank sands. The available data suggest that the source material for the oil in the Arbuckle and Hominy sand zone and the "Mississippi lime"-Burgess sand zone is in the beds overlying the unconformities, namely, in the Simpson formation and in the Cherokee shale. The encroachment of the Simpson sea upon the erosion surface on the Arbuckle limestone and the encroachment of the Cherokee sea upon the erosion surface on the "Mississippi lime" was not accomplished suddenly and uniformly over the region. The evidence revealed by the abrupt variations in the character of the rocks in the lower parts of these two formations indicates that conditions were extremely irregular. The sediments accumulated on irregular surfaces and the shorelines doubtless flucutated back and forth many times. Thus, a thin bed in contact with the unconformity at one place is likely to be of slightly different age than such a bed overlying the unconformity at other places nearby. Under these conditions, irregularity of environment would be the rule in contrast to a general uniformity that is believed to have prevailed at the time of the deposition of the Burbank sand.

Inasmuch as both the Arbuckle limestone-Hominy sand zone and the "Mis-

sissippi lime"-Burgess sand zone are prolific yielders of water, it would appear that these zones afforded ideal conditions for the migration of oil. The most opportune time for large-scale migration would have been at the time of accumulation of the oil into pools, and at the several times when regional tilting of the rocks occurred.[21] If the oil migrated over any considerable distance throughout a sizeable area, however, many pools in a given area should contain similar oil. The fact that the oils in these zones are not similar but are highly variable from pool to pool suggests that such migration has not taken place.

The loss of a portion of the very volatile fractions of an oil during a long period of production, described under the chapter on the Burbank sand pools, suggests a possible explanation for the low-gravity oils in the Arbuckle limestone in southeastern Kansas, that are tabulated in Table III. One of the striking features of these oils is that they contain none of the lighter fractions; they vary rather widely, however, in this respect. The oils have the appearance of having been weathered. None of the oils from the pools in Kansas east of R. 9 E. yielded, upon distillation by the Hempel method, more than 3.5 per cent up to a temperature of 200°C., which is the highest temperature reached in the 7th fraction. The total amount yielded up through the 7th fraction for the oil in the Pond Creek pool in Oklahoma is 5.7 per cent.

Some events in the geologic history of the region suggest that these oils have had opportunity to have been weathered, provided they originated not long after the deposition of the Chattanooga shale, which is the formation that directly overlies the reservoir beds. All these oil pools are in porous beds of dolomite at the top of the Arbuckle limestone that were exposed for a long time prior to their burial by the Chattanooga shale. Beds of the Chattanooga may be the source beds for the oil.[22] The Chattanooga shale is absent in many small tracts in the region and in a large area including most of central and northern Osage County, northeastern Kay County, Oklahoma, and southern Chautauqua County and southeastern Cowley County, Kansas.[23] The shale is only a few feet thick near the margins of the shale-free areas. The Chattanooga is not known to contain material that suggests that the shale-free areas stood as islands during the time the Chattanooga was being deposited. It appears likely, therefore, that the shale was deposited over the entire region and was eroded not long thereafter. The upper boundary of the formation is known to be disconformable with the overlying Mississippian rocks, locally in northeastern Oklahoma[24] and in southeastern

[21] A. I. Levorsen, "Studies in Paleogeology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 9 (September, 1933), pp. 1120–23.

[22] W. H. Foster, "Coffeyville Oil Field, Montgomery County, Kansas," *Structure of Typical American Oil Fields*, Vol. I, Amer. Assoc. Petrol. Geol. (1929), p. 50.

[23] Constance Leatherock and N. W. Bass, "Chattanooga Shale in Osage County, Oklahoma, and Adjacent Areas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 1 (January, 1936), Fig. 1, p. 92.
Wallace Lee, "Subsurface Mississippian Rocks of Kansas," *Kansas Geol. Survey Bull. 33* (1940), Pl. 3.

[24] J. A. Taff, "Tahlequah, Indian Territory (Oklahoma)-Arkansas," *U. S. Geol. Survey Folio 122* (1905), p. 3.

Kansas.[25] The time of accumulation of the oil pools is unknown; they may have formed prior to the post-Chattanooga erosion period. If so, this erosion period might have afforded opportunity for the escape of the more volatile constituents of oil from pools lying beneath the Chattanooga shale but close to the margin of the eroding areas. Abernathy[26] has shown that in parts of the Chetopa pool (see No. 12, Fig. 7, and Table III), wherein the reservoir cap rock is absent, oil has probably migrated from porous dolomite of the Arbuckle into the overlying Chattanooga shale. It is noteworthy that the pools in western Cowley County, which contain normal oil having the ordinary amount of volatile constituents, are in an area where the Chattanooga shale appears to have its full thickness.

It has been suggested that the infiltration of meteoric waters in the Arbuckle porous zones in this area has weathered the oils. Abernathy[27] called attention to the small content of dissolved solids (1,583 parts per million) in the water associated with the oil in the Chetopa pool. Dott and Ginter,[28] and later Case,[29] have shown that the amount of total solids in the waters in the Arbuckle is small in southeastern Kansas and increases southwestward. According to these authors' iso-con maps, most of the pools whose oil contains none of the light fractions lie in the area having water with a low content of solids. In general, the amount of light fractions in the oils increases westward, which is the direction of increase in the concentration of solids in the waters. The Ordovician waters in western Cowley County, where pools of normal high-gravity oil occur in the Arbuckle, contain 50,000 or more parts per million of total solids. The writers hesitate to suggest that the oils have been weathered by the waters associated with the oils, however, because elsewhere, particularly at several places in the Rocky Mountains region,[30] nearly fresh water is associated with high-gravity oils having a normal or even greater than ordinary content of volatile fractions. For example, in the Rattlesnake field near Shiprock, New Mexico, although the water from the Dakota sandstone is suitable for camp use, the oil from this sand has an A.P.I. gravity of 76° and the entire crude oil is composed of hydrocarbons that distill off in the first five fractions obtained in a Hempel-method analysis.

[25] Wallace Lee, *op. cit.*, p. 21.

[26] G. E. Abernathy, "Migration of Oil from Arbuckle Limestone into Chattanooga Shale in Chetopa Oil Pool, Labette County, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 10 (1941), pp. 1934–35.

[27] G. E. Abernathy, *op. cit.*, p. 1936.

[28] R. H. Dott and R. L. Ginter, "Iso-Con Map for Ordovician Waters," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 9 (1930), p. 1216.

[29] L. C. Case, "Subsurface Water Characteristics in Oklahoma and Kansas," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), pp. 856–58.

[30] R. C. Coffin and R. K. DeFord, "Waters of the Oil- and Gas-Bearing Formations of the Rocky Mountains," *ibid.*, pp. 947–51.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 1 (JANUARY, 1947), PP. 149-158, 1 FIG., 1 PLATE.

GEOLOGICAL NOTES

ORDOVICIAN AND SILURIAN ROCKS IN YUKON TERRITORY, NORTHWESTERN CANADA[1]

CHARLES E. DECKER,[2] P. S. WARREN,[3] AND C. R. STELCK[4]

INTRODUCTION

In a region where the age of the rocks was unknown, the diagnostic graptolites were collected, giving the significant evidence of the presence of Lower and Upper Ordovician, and Silurian horizons. C. R. Stelck, the collector, deposited the fossils at the University of Alberta where they were given accession numbers. The graptolites from these collections were forwarded to the senior writer for identification by P. S. Warren, head of the department of geology at the University of Alberta, Edmonton, Alberta.

LOCATION

The collections were made about 100 miles south of Fort McPherson by C. R. Stelck along the Peel River, a western tributary of the Mackenzie River near its mouth. This area is in Yukon Territory in far northwestern Canada. It is on the northeast side of the Mackenzie Mountains near the Arctic Circle, between 65° 30′ and 66° N. Lat. and 134° 30′ and 135° 30′ W. Long. The collections were made from three localities along the lower canyon of the Peel River, and seven more of them 10 to 20 miles farther upstream near the confluence of the Wind and Peel rivers. The senior writer has numbered the ten localities shown on the small-scale outline map (Fig. 1), beginning with those farthest upstream. The north edge of the map is about 40 miles south of Fort McPherson.

STRUCTURE

The strike of the rocks is in general northwest-southeast with an anticline near the middle of the area. There is overturning in the lower canyon at the northwest, and on the south, upstream, the rocks dip about 30° SW. Strong tangential pressure has affected some of the rocks, making them somewhat slaty or schistose.

NATURE OF COLLECTIONS

The collections include sponge spicules, corals, graptolites, brachiopods, and bryozoans. Graptolites were obtained from eight of the ten localities. Much of the

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graptolite material is very fragmental, and some is very indistinct due to metamorphism and foliation of the rocks. Though some of the fragments are small, they seem to represent the more resistant parts of the colonies, and these parts seem sufficiently characteristic of the species to be diagnostic. Similar fragments of the species have been preserved in various parts of the world, and they have been illustrated in numerous publications. Thus their use in correlation seems jus-

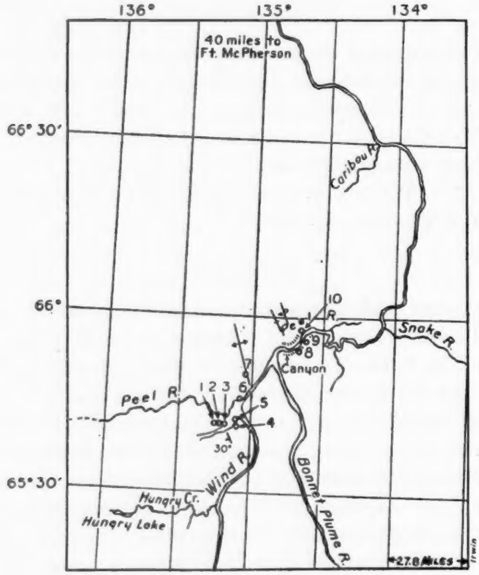


FIG. 1.—Map by C. R. Stelck, showing 10 fossil localities along Peel River in Yukon Territory, northwest Canada. Redrawn by Jessie Beth Irwin by courtesy of Oklahoma Geological Survey. Number of fossil suites and accession numbers listed on Stelck's original map are placed by localities in Table 1.

tified, especially where they are associated with more complete forms representing the same horizon.

Information by C. R. Stelck shows the condition of the rocks at localities 8, 9, and 10, with a detailed section of the beds in the lower canyon in the vicinity of the localities 9 and 10. Beginning at the lower end of the canyon, the measured section consists mostly of shales with a total thickness of 2,614 feet. The total thickness of the beds in the lower canyon consists of the 2,614 feet in the measured section, plus 1,500 feet of shales and argillites upstream at locality 8, making in all 4,114 feet. Information and detailed section by Stelck follow.

PEEL RIVER SECTION OF ORDOVICIAN-SILURIAN ROCKS

C. R. STELCK

Ordovician.—Two horizons of graptolites (Suites 3,815, 3,816) were collected from the center of this section of 1,500 feet of beds of thin-bedded shales and argillites.

Silurian?—A section of shales and argillites in an overturned section measured 2,614 feet of beds. An arbitrary division was made with the Ordovician beds at the base of a bed of black limestone that is 50 feet thick, brecciated and conglomeratic.

A detailed section of the Silurian? beds in the lower canyon reveals the following lithology (beginning at the north end of the canyon, measuring southward upstream).

Feet	
	Shales and conglomerates of Devonian age. Contact, unconformable
250	Shales, black, soft, graptolite Suite 3,819 at top
20	Argillite, thick-bedded, limy
120	Shales, nodular with thin argillites and thin coquina bands (Suite 3,818)
60	Argillites, dark with interbedded shales
67	Shales, soft fissile
20	Shales, soft with graptolites (Suite 3,817)
72	Shales, slaty, dark gray
66	Shales, fissile with marcasite
20	Shale, hard with graptolites (Suite 3,811)
20	Shales with graptolites and thin crinoidal limestone (Suite 3,810)
8	Shales, silty
12	Shales, silty with graptolites (Suite 3,809)
12	Shales, silty with graptolites (Suite 3,808)
10	Shale, dark gray
50	Shales, with some 4-inch bands of argillite
30	Shales, somewhat platy (Suite 3806)
20	Shales, thin, fissile
21	Shales with graptolites (Suite 3,805)
100	Shales with some marcasite, containing thin beds of crinoidal limestones (Suite 3,807)
72	Shales, clay-weathering and silty shales
90	Shales, fissile, with thin black argillitic limestone bands
3	Shales with graptolites (Suite 3,804)
54	Shales, silty with interbedded clean shales and thin argillitic limestones
42	Shales with rusty streaks and thin argillites
1	Limestone, shaly
3	Shale, fissile, marcasitic
51	Shale, limy, gray weathering
48	Shale, black, fissile
6	Argillites, silty bedded
12	Shales, rusty, slaty
12	Shales, rusty, sulphurous, fissile
9	Shales, siltv, thick-bedded
2	Shales, dark, gray
3	Argillite, calcareous with siltstones
6	Shales and argillites, very thin-interbedded
10	Shales, silty with interbedded thin calcareous siltstones
20	Shales, dry gray
8	Shales and thin-bedded calcareous argillites
30	Shales with here and there an argillite bed
6	Argillites, calcareous with shale
12	Shales, with thin argillites
5	Limestone conglomerate, shales, crinoidal limestones with corals (Suite 3,803)
2	Shales with graptolites (Suite 3,802)
6	Shales with thin sandy conglomerate streak
6	Argillite, lime conglomerate and shales
20	Argillites, massive, with thin shales

11	Shales, thin-bedded, angular weathering
1	Shale with fossiliferous lime nodules
8	Shale, slaty with bedded sheared planes
3	Shale, fissile with nodules of argillites
6	Shales, thin-bedded
36	Argillites and shales, developing slaty habit
20	Shales, silty, showing crossbedding, grading into shales
16	Shales, dark gray, thick bedded
20	Shales, gray brown, light-weathering
6	Shales, gray, thick-bedded
40	Shales, gray, marly, thin-bedded, soft
80	Shales, concealed in part but containing crinoidal lime conglomerate bed (Suite 3,801)
300	Shales and argillites with Suite 3,813 from near base
500	Shales and argillites with Suite 3,814 from near base (concealed in south side of canyon)
50	Limestone, black brecciated with some limestone conglomerate
2,614	
	Contact, apparently conformable
	Shales and argillites of Ordovician age

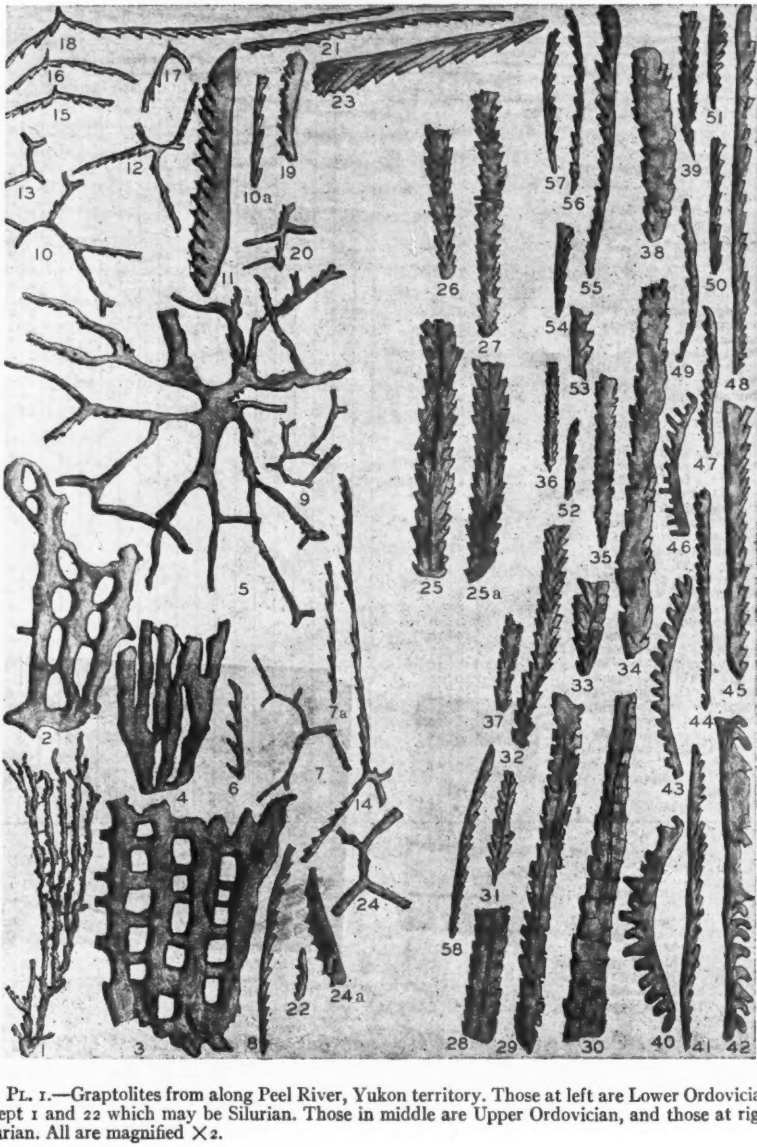
Numbers of the fossil collection suites, originally listed by localities on the map and their corresponding accession numbers at the University of Alberta, are shown for each of the 10 localities in Table I, together with the age determinations by the senior writer.

TABLE I

Locality	*Suites*	*Accession*	*Locality*	*Suites*	*Accession*	*Locality*	*Suites*	*Accession*
1 Sil.	3,797	—42,904	9 Sil.	3,801	—42,847-50	10 L. Ord.	3,817	—42,901
2 Sil.	3,796	—42,887	and	3,802	—42,893		3,818	—42,815
		42,812	U. Ord.	3,803	—42,814		3,819	—42,834
3 Sil.	3,795	—42,813			42,864-66		3,820	—
		42,888		3,804	—42,880		3,821	—
4 ?	3,794	—42,854		3,805	—42,863		3,822	—
		42,862		3,806	—42,877		3,823	—
5	41,133	— —		3,807	— —		3,824	—
6 ?	42,851	—42,851		3,808	—42,842		3,825	—
7	42,821	—42,821		3,809	—42,861		3,826	—
	42,822	—42,822		3,810	— —			
	3,812	—42,873		3,811	—42,819			
8 L. Ord.	3,815	—42,867		3,813	—42,881			
	3,816	—42,872		3,814	—42,832			
				—	—42,843			

In Table II, the species of graptolites are listed in three main groups, Silurian Upper Ordovician, and Lower Ordovician, with two forms (Figs. 1 and 22), questionable as to age.

The Silurian species occur far upstream at localities 1, 2, and 3, and near the lower end of the canyon at locality 9. This group includes 7 Silurian forms in the genus *Diplograptus*, 1 in *Climacograptus*, 1 in *Cephalograptus* and 14 in *Monograptus*. One of these species is found in the Silurian of Greenland, 1 in Maine, Illinois, and West Texas well, and 3 in Oklahoma. All of them occur in Great Britian and a number in Norway, Sweden, Denmark, Germany, and Bohemia, and a large number in Australia.



PL. 1.—Graptolites from along Peel River, Yukon territory. Those at left are Lower Ordovician, except 1 and 22 which may be Silurian. Those in middle are Upper Ordovician, and those at right Silurian. All are magnified ×2.

TABLE II

LIST OF SPECIES BY AGE, FOSSIL LOCALITY FOR EACH, FIGURE NUMBER FOR PLATE 1, AND DISTRIBUTION OF SPECIES THROUGHOUT WORLD

SILURIAN SPECIES	*Collecting Localities—1; Figures on Plate 1; Distribution, 3–22*																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Diplograptus bellulus	2	35											x	x							x	
Diplograptus modestus	2	33											x		x					x	x	
Diplograptus modestus parvulus	1	31											x									
Diplograptus persculptus	2	29, 34, 38											x									
Diplograptus tamariscus	1	36											x			x	x	x			x	
Diplograptus tamariscus incertus	1	32											x									
Diplograptus vesiculosus	1	28											x				x					
Climacograptus tornquisti	2	37											x				x					
Cephalograptus acuminatus	9	39											x									
Monograptus cf. atavus	9	52											x									
Monograptus cf. comis	9	41											x								x	
Monograptus cf. concinnus	9	55, 58											x									
Monograptus dubius	1	54								x			x			x				x	x	
Monograptus cf. gotlandicus	9	53											x							x		
Monograptus jaculum	9	44											x			x				x	x	
Monograptus cf. leptotheca	9	50		x									x			x	x			x	x	
Monograptus nilssoni	1	56, 57					x			x			x			x	x	x		x	x	
Monograptus cf. pandus	3	42											x							x	x	
Monograptus raitzhainiensis	2	40, 43, 46											x			x		x				
Monograptus cf. runcinatus	9	49											x			x	x			x	x	
Monograptus tumescens	9	45								x			x					x				
Monograptus variabilis	9	47											x							x		
Monograptus cf. vomerinus	9	48							x		x		x							x	x	
UPPER ORDOVICIAN SPECIES																						
Diplograptus angustifolius	9	27	x		x			x				x									x	
Diplograptus euglyphus	9	26	x		x			x				x									x	
Diplograptus teretiusculus	9	25, 25a											x	x							x	
LOWER ORDOVICIAN SPECIES																						
Dictyonema murrayi	8	2			x		x															
Dictyonema quadrangularis	8	3			x																	
Dictyonema robusta	8	4			x																	
Goniograptus flexilis	8	5			x																	
Goniograptus cf. palmatus	8	6																			x	
Goniograptus cf. perflexilis	8	7, 7a						x														
Goniograptus cf. thureaui	8	8			x			x													x	
Loganograptus cf. rectus	8	9																			x	
Dichograptus cf. expansus	8	10, 10a																			x	
Dichograptus cf. octonarius	10	19																			x	
Dichograptus octonarius solida	8	11																			x	
Staurograptus cf. dichotomous	8	12				x		x														
Sigmagraptus cf. praecursor	10	20						x														
Tetragraptus cf. decipiens bipateus	8	13																			x	
Tetragraptus quadribrachiatus	8	14, 24, 24a			x	x		x					x	x					x		x	
Bryograptus cf. lapworthi	8	15, 16						x														
Didymograptus cf. filiformis	8	17						x					x			x		x				
Didymograptus cf. nicholsoni	8	18, 21						x					x									x
Didymograptus cf. sparsus major	10	23								x												
POSSIBLY SILURIAN																						
Dictyonema sp.?	4	1																				
Monograptus fragment?	6	22																				

KEY TO COLUMNS

1. Collecting localities
2. Plate figures
3. Deese River, British Columbia
4. Greenland
5. Quebec, Canada
6. New Brunswick
7. Maine
8. New York
9. Illinois
10. Oklahoma
11. West Texas well
12. Nevada
13. Great Britain
14. Scandinavia
15. Norway
16. Sweden
17. Denmark
18. Germany
19. France
20. Bohemia
21. Victoria, Australia
22. New Zealand

The Upper Ordovician species are from one of the collections obtained at locality 9. They doubtless should occur between the Silurian at this locality and the Lower Ordovician found at 8 a little farther upstream. Two of these Upper Ordovician forms occur at Deese River, British Columbia, 2 near Quebec, Canada, 2 in New York, 2 in Nevada, 3 in Australia, 1 in Great Britain, and 1 in Scandinavia.

The Lower Ordovician species were obtained from only two localities, 8 and 10, at lower end of the canyon. The Lower Ordovician forms illustrated in Plate 1 (Figs. 2–23), are chiefly fragments of large complex colonies. Only very small fragments are shown of the 3 *Dictyonemas murrayi, quadrangularis,* and *robusta.* A complete colony is so large that it would cover about one-fourth of a plate. All three of these species were described and illustrated from the Quebec region of Canada by James Hall, as was also *Goniograptus flexilis,* the central part of which is shown in Figure 5. The fragments of colonies shown in Figs. 6–13, 19, and 24 represent either the central parts of compound colonies, or individual stipes of such colonies. Fragments of these forms are particularly well illustrated from the Lower Ordovician of New York and Australia. The assemblage as a whole gives very clear evidence of Lower Ordovician.

To summarize briefly, the Silurian species come from map localities 1, 2, 3, and 9, the Upper Ordovician from a collection at 9, and the Lower Ordovician from localities 8 and 10, and most of these forms show a very wide geographical distribution.

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PRODUCTION AND RESOURCES OF PETROLEUM IN JAPAN[1]

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INTRODUCTION

Petroleum production in Japan is limited to northwestern Honshu and central Hokkaido. The known oil-producing beds are in Tertiary formations of Miocene and Pliocene age. The main producing areas of northwestern Honshu are in the Akita, Yamagata, and Niigata Tertiary embayments. The producing areas in Hokkaido are the Kitami, Ishikari, and Atsuma districts.

STATUS OF INDUSTRY

The Imperial Oil Company, an organization in which the ownership is divided equally between the Japanese Government and private interests, controls nearly 95 per cent of the total crude-oil production of Japan; the remaining 5 per cent is produced by several small independent companies.

Salient statistical data of the oil-producing industry may be summarized as follows.

	*Kiloliters**	*Barrels*
Total production, 1874 to March, 1946	14,283,207	89,841,372
Estimated developed reserve	2,475,500	15,570,000
Total production, fiscal year ending March, 46	235,704	1,482,578
Number of fields producing, March, 46	50	
Number of wells producing, March, 46	4,190	
Average daily production per well	0.97 barrel	
Total area developed	11,455 acres	
Average indicated recovery, Hokkaido	875 barrels per acre	
Average indicated recovery, Northwest Honshu	10,000 barrels per acre	
Average indicated recovery (best fields)	35,000 barrels per acre	
Over-all drilling density	1.1 acres per well drilled	

* 1 kiloliter equals 6.29 barrels.

[1] Published with the permission of the chief of the Natural Resources Section. Manuscript received, December 6, 1946.

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The industry has struggled to develop intensively resources of a lean and complex character, scattered over many small fields. As shown by the statistics, the industry has been a relatively small one and most wells have now reached the stripper stage. In recent years the industry has supplied only a fraction of Japan's oil requirements and barely supplies one-third of the much reduced minimum requirements under the occupation.

The proved oil reserves, as estimated by production-decline curves, can be lifted only at an average cost above world levels. The proved reserves of undrilled oil and gas appear to be trivial. The industry is operating with Government support. The future of the industry is dependent on finding new fields, the presence of which remains to be proved.

Direct contact with American practices before the war was largely limited to interest in drilling methods and equipment. This explains the relatively up-to-date character of the drilling organization. The Imperial Oil Company has adequate resources in equipment[3] and trained personnel for a substantial drilling program. On the other hand, the application of geologic science to oil exploration in Japan has found little practical expression beyond the methods and views prevailing in the United States and in other oil-producing countries during the 1920's. Even in producing districts, much remains to be learned about oil potentialities. Areal geologic mapping is incomplete, and no compilation maps are ready for publication. Geophysical methods, to obtain data over extensive and significant alluvial areas, have been used on a small scale only during the last 3 years. Subsurface studies, inspired by experience in the East Indies during World War II, are still rudimentary. Micropaleontologic studies have not passed the basic research stage and have not been applied to regional correlation. In the fields, drilling superintendents have continued to exercise a dominant influence on development policy.

FUTURE PROSPECTS

Although the geological picture and past records of the producing districts do not encourage the expectation of major discoveries, undoubtedly significant territories remain both within and outside the present producing districts which are either very imperfectly known or to which modern exploratory technique has not yet been applied.

An estimate of the possible but unknown reserves of the producing districts of northwest Honshu attributes to these districts a figure of 14,000,000 kiloliters plus a speculative substantial amount that may possibly be derived from basal Miocene beds below present producing zones.

Although the recovery per acre in Miocene fields of central Hokkaido is so low that it is practically uneconomic, no tests have been made or planned of Paleogene and Cretaceous formations that are oil-bearing in outcrops. More

[3] J. C. Fortune, "Japanese Petroleum Drilling Methods and Equipment," *Natural Resources Section Rept. 49* (August 7, 1946). 49 pp., 8 figs. in text.

favorable structural conditions appear to be present in this area than in northwest Honshu. If these deeper beds are proved productive, larger fields than those yet found in Japan could result. Many areas are not fully mapped and further structures may be found.

No attention has been given by the Imperial Oil Company to prospects in other sedimentary basins which, apart from reconnaissance many years ago by the Imperial Geological Survey, have received little attention. Oil seepages occur in eastern Hokkaido where there is a largely unmapped Tertiary basin. Other Tertiary embayments are found on the Pacific coast of Honshu. One of these is at Sagara, in Shizuoka Prefecture, where small qauntities of oil have been produced. The nature of the formations underlying the post-Pliocene deposits of the large Kwanto Plain, on the margin of which are oil indications, is conjectural. This does not exhaust the list of possible areas.

PRESENT PROGRAM

The size of the Imperial Oil Company's drilling organization outweighs the immediate ability of its geologists to find profitable employment for it. The magnitude of the original drilling program proposed by the Imperial Oil Company for the fiscal year ending March 31, 1947, was inspired by the desire to maintain in employment as many as possible of the staff and labor force, many of whom were repatriated from the East Indies, rather than by consideration of proved reserves or geological prospects ripe for exploratory drilling. Circumstances have combined to throw this program well behind schedule, and the program for the second half of the year will probably be reduced from the 51 strings of tools originally planned to about 35 strings, eliminating some of the doubtful locations and reducing waste of drilling materials.

The results of this drilling program, however, will not give a true reflection of the remaining possibilities of those districts or fields.

Geological exploration has been resumed, but is limited to the producing districts. Most of the major prospects remaining in these districts lie in alluvial areas. In these areas progress may be slow because of shortage of geophysical instruments and trained personnel. During the winter months, when work in the field is impracticable, the geologists will concentrate on compilation work and studies of a regional nature. Exploitation engineers will continue subsurface studies of the fields. The picture thus obtained should provide them with a sounder geological basis for future exploration and development policy and enable a more appropriate balance to be reached between immediate potentialities and scale of operations.

The Ministry of Commerce and Industry has under review the whole future of the crude-producing industry.

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DISCUSSION

KINDERHOOK DOLOMITE OF SEDGWICK COUNTY, KANSAS[1]

R. A. CARMODY[2]
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W. A. Ver Wiebe in a recent paper[3] fails to mention the presence of an upper Ordovician, Maquoketa or Sylvan, shale in the area of his report. For the benefit of any future workers in this area, it should be recorded that many Kansas geologists, including the writer, have noted a shale in the subsurface of this area which is believed to be upper Ordovician in age. This shale is generally mouse-gray in color, non-micaceous, varies from slightly to decidedly dolomitic, is clayey rather than fissile, and, instead of "*Sporangites*" (*Tasmanites* sp.), contains microscopic black carbonaceous rectangular graptolite fragments.

Shale of the foregoing description has been found at the position of the "Lower shale," Figure 1, page 1749,[4] which Ver Wiebe describes as black shale with spores and which he believes to be Mississippian in age. Those who recognize any Ordovician shale in samples at that horizon would interpret the presence of any black spore-bearing shale, no matter how great the percentage, as having caved from the Chattanooga shale, "Upper shale" of Figure 1.

There is little question that Maquoketa or Sylvan shale is one of the most difficult to identify with confidence, of all the more important stratigraphic markers in the subsurface of Kansas. The writer has heard many geologists, particularly those with limited experience in microscopic sample examination, express concern over their inability to establish a criterion for the recognition of this upper Ordovician shale in well cuttings.

One of the principal reasons for this difficulty appears to lie in the character of the formation itself. Ordinarily clayey and dolomitic in texture, it disintegrates rather rapidly in the presence of water and in collision with other particles, and thus most of it is washed out of ordinary rotary samples as mud. In cable-tool drilling, much of the formation is churned and ground into mud by action of the bit. The few fragments remaining in the average rotary sample, and commonly in cable-tool samples, are easily overlooked midst the cavings from younger formations. Fissile shales such as those in the Chattanooga and Pennsylvanian, which withstand the wear and tear of drilling and washing much better, ordinarily furnish the bulk of such cavings.

If there is an upper Ordovician shale instead of a Mississippian shale immediately below this dolomite of controversial age, then there is no conclusive evidence for placing this dolomite in the Kinderhook and Mississippian as advocated by Ver Wiebe.

As stated by Ver Wiebe, early in his paper, the name Hunton is most frequently applied to this dolomite by Kansas geologists. Those of us who subscribe to that correlation do so in the belief that it is older than Chattanooga or so-called Kinderhook shale. Misener sandstone, the basal unconformity sand of the Chattanooga, is found above it in many places. Ver Wiebe even points out a few occurrences in his paper. Since ever increasing

[1] Manuscript received, November 25, 1946.

[2] Gulf Oil Corporation.

[3] W. A. Ver Wiebe, "Kinderhook Dolomite of Sedgwick County, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 10 (October, 1946), pp. 1747-55.

[4] *Ibid.*

paleontologic[5] and stratigraphic evidences indicate a Devonian rather than a Mississippian age for the overlying Chattanooga shale, there is good reason for believing the still older dolomite to be Siluro-Devonian (Hunton) in age.

In northern Harvey County, only a few miles north and northwest of the area studied by Ver Wiebe, the identification of Devonian and possibly Silurian fossils has been reported from cores and cuttings of limestone and dolomite at the same stratigraphic position as Ver Wiebe's Kinderhook dolomite. These fossils came from a number of wells in the Hollow field,[6] T. 22 S., R. 3 W., and from one well in the Sperling field,[7] T. 22 S., R. 2 W.

The writer agrees with Ver Wiebe that there is no shale, at least none thick enough to pick up in samples, between Viola and Hunton (Kinderhook dolomite of his report) in the wells he mentioned, page 1755. This overlap of Hunton on Viola is the rule rather than the exception over a large area immediately south and east of the southeastern edge of the area, Figure 2, page 1750, which he studied. Hunton dolomite, which rests directly on Viola dolomite, is the principal producing formation of the Greenwich field in Secs. 14 and 15, T. 26 S., R. 2 E., Sedgwick County, Kansas. This interpretation is in disagreement with Bunte,[8] who included both dolomites as Viola in a paper on this field.

[5] Samuel P. Ellison, Jr., "Conodonts as Paleozoic Guide Fossils," *Bull. Amer. Assoc. Petrol Geol.*, Vol. 30, No. 1 (January, 1946), pp. 93–110.

[6] Leslie A. Johnston, "Pre-Pennsylvanian Stratigraphy of the Hollow Pool and Adjacent Areas of the Central Kansas Basin," *Tulsa Geol. Soc. Digest* (1934), pp. 12–17, especially pp. 13–14.

[7] Roy Hall, "Age of So-Called Hunton Limestone of Southern McPherson and Northwestern Harvey Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 2 (February, 1934), p. 266.

[8] Arnold S. Bunte, "Subsurface Study of Greenwich Pool, Sedgwick County, Kansas," *Bull Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 5 (May, 1939), pp. 643–62, especially 649.

GEOLOGY OF MARACAIBO BASIN, VENEZUELA CORRECTION

In the article by F. A. Sutton, "Geology of Maracaibo Basin, Venezuela," in the *Bulletin*, Vol. 30, No. 10 (October, 1946), p. 1712, footnote, the correct spelling of the name of the formation that is suggested as a substitute for the name Dividive is CARVAJAL, not Caravajal.

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RESEARCH

REPORT OF SUB-COMMITTEE ON STRATIGRAPHY AND SEDIMENTATION[1]

MARSHALL KAY,[2] Chairman
New York City

The sub-committee was organized during the summer of 1945; after preliminary correspondence, some of the members and consultants met at the Geological Society of America convention in Pittsburgh, in December, to consider functions and procedures. The principal purpose of the sub-committee on stratigraphy and sedimentation was deemed to be to analyze the state of research in these fields so as to suggest research that might be most productive in advancing fundamental knowledge of subsurface stratigraphy, and thus improve the facility of geologists in finding and recovering oil. Subsequently, a preliminary report, and analyses of the state of research in stratigraphy, sedimentation and sedimentary petrology, and oceanography were prepared as bases for discussion of specific projects and problems; the summaries are appended to the present report. The group considered specific proposals on March 31, prior to the Association convention in Chicago; a tentative report was outlined, and revised after the open conference on research needs in stratigraphy and sedimentation on April 1. The report is respectfully submitted.

The sub-committee classified projects into (a) those that promise results of general interest and value, and that are well organized or seem possible of formulation within a few months, (b) those seeming similarly promising that are now being undertaken, and (c) those needing further consideration and formulation, or comprising studies that should be made by local groups or individuals.

The sub-committee recommends that the research committee include in its report to the executive committee of the Association:

The following are projects of fundamental character that have been formulated, or should be so within a reasonable time; they warrant such action by the Association as will encourage their prompt prosecution:

1. Investigation of the sediments of the northern part of the Gulf of Mexico with reference to the physical, chemical and biological factors in their environment.
2. Investigation of the nature and manner of origin of porosity and permeability in carbonate rocks.
3. Comprehensive study of the sediments of a single limited stratigraphic section over a considerable area.
4. Investigation of the cementation of sedimentary rocks and its bearing on oil occurrence.
5. Standardization in the recording of routine laboratory work, in order that results may be more readily applied in later research.

The following are projects of research or compilation of general interest and value that are being undertaken; they are commended as warranting such cooperation and support as can be given by the Association:

[1] This is the second of the "Final Reports on a Reconnaissance Survey of Research Needs in Petroleum Geology by the American Association of Petroleum Geologists Research Committee, 1945–1946." The first, "Report of Sub-Committee on Tectonics," by Philip B. King, was published in the *Bulletin*, Vol. 30, No. 12 (December, 1946), pp. 2040–63.—S. W. Lowman, chairman, research committee.

[2] Department of geology, Columbia University, April 15, 1946. The sub-committee on stratigraphy and sedimentation is composed of the following: R. K. DeFord, W. C. Krumbein, W. W. Rubey, W. H. Twenhofel, and Marshall Kay, *chairman;* H. V. Howe, H. S. Ladd, F. B. Phleger, F. W. Rolshausen, F. P. Shepard, H. C. Stetson, Parker Trask, and C. E. ZoBell, consultants.

1. Investigation of the bottom of the Gulf of Mexico off the continental shelf, a project of the Woods Hole Oceanographic Institution.

2. Publication of regional paleogeographic maps in programs of the Fuels Section, United States Geological Survey, state surveys and individuals.

3. Preparation of a book on paleoecology planned by the Committee on Marine Ecology as Related to Paleontology, National Research Council.

4. Revision of the *Treatise on Sedimentation* proposed by the Committee on Sedimentation, National Research Council.

The sub-committee received suggestions of fields in which many separate projects can be devised. Among these proposals, several seem particularly worthy of encouragement:

1. Investigations of effects of turbulence and current velocities on sediments.
2. Investigations of the chemistry of diagenesis.
3. Classifications of geosyncline and the larger stratigraphic units.
4. Preparation of comprehensive bibliographies of biologic groups.
5. Assembling and publication of lists of faunas in formations and larger rock units.

The following are contributions made by members of the sub-committee and consultants in their endeavor to summarize the research needs in several fields:

An Analysis of Stratigraphy, by Marshall Kay
An Analysis of Sedimentation and Diagenesis, by W. C. Krumbein
Oceanography as Related to Petroleum Geology, by Henry C. Stetson and Fred B. Phleger, Jr.
Submarine Geology Studies in the Pacific, by Francis P. Shepard
Progress of Studies Relating to Microbiology of Sediments, by Claude E. ZoBell

The chairman appreciates the continued cooperation of members of the sub-committee and consultants, and the valued suggestions and guidance of the research committee and officers of the Association.

ANALYSIS OF STRATIGRAPHY

MARSHALL KAY[1]
New York City

INTRODUCTION

The present methods in stratigraphic geology reflect the great interest in the science during the past few decades, particularly in the search for petroleum. Stratigraphy, dealing with the nature and development of the sedimentary rocks of the earth, is the inorganic part of historical geology. The presence and character of sediments are dependent essentially on crustal deformation; depressions received deposits yielded by areas that had been elevated. Stratigraphy is veritably the interpretation of the record of progressive movements evidenced in sedimentation. Paleontology is a means by which rocks are better classified in time and in environment of origin. The principles of stratigraphy are continuously better understood with the increment of knowledge and consideration, and many methods have been devised to enable better judgment. The accuracy of reported relations depends on the propriety of the interpretations.

Methods differ in varying degrees in surface and subsurface studies, and in local, regional, and interprovincial problems. In each, there must be record of characters in specific sections. Perspective can be gained by comparing present knowledge with that when Ulrich and Grabau considered the methods 30 years ago.

[1] Professor of Geology, Columbia University.

DESCRIPTIONS OF SEDIMENTARY SEQUENCES

Sedimentary petrology.—There has been accelerating development and application of sedimentary petrology. The directly described characters of rocks include color, size, shape, and arrangement of particles, chemical and mineral composition, and structure. Endeavors to standardize color designations have not brought significant effect on the work of most investigators. The methods of description of particles in unconsolidated and readily disintegrated rocks have made such progress that there has come to be precision in place of the cursory descriptions of the past; statistical treatment of the facts permits segregation of significant factors. Progress is now appearing in the comparable study of consolidated sediments. These improved techniques have been applied in descriptions of present deposits, rock exposures and subsurface cores. The development of methods permits almost limitless discrimination and synthesis. The degree to which such work should be expanded will depend on the gains from its employment; compilation of voluminous data may in some instances not yield commensurate returns. Much that has been done may not appear in print, but it is one's impression that comprehensive studies are rare.

Geophysics.—Geophysical records bearing directly on lithology have come into increasing use in subsurface descriptions in the past ten years. Resistivity and self-potential electric logs reflect the differing physical states of successive sedimentary layers and zones. Most recently, logs recording radioactivity as well as the adsorption of emanations have been introduced. Each must be interpreted to permit conversion to lithology. Most have distinct advantage in presenting relatively readily obtained continuous records that contrast with the selected and somewhat mixed samples that are gained, permitting sharp definition of lithologic changes, particularly in rocks having frequently varying characters. Moreover, they reflect the nature of the fluids as well as the solids. In some areas, cruder records have been given by drilling-time logs. The geochemistry of fluids has been a subject of some study.

Paleontology.—The fossil content of beds may be considered as part of their description, quite aside from its biologic aspects. Surface exposures have considerable advantages in permitting recognition of forms of larger fossils that will be preserved only in cores from wells, and in giving access to large areas on the most richly populated surfaces. There has been continued addition to our knowledge of most classes of organisms, and marked refinement in discrimination in some. Moreover, faunas in parts of the geologic record have been discovered largely in the past few years, particularly in some sequences having important subsurface petroleum developments. Subsurface studies have expanded investigations of fossils of small size, practically forming the science of micropaleontology. Foraminifera and Ostracoda have been studied extensively; radiolarians, diatoms, conodonts and other groups in limited areas and sections.

CORRELATION

Nature and significance.—The comparison of two or more sections constitutes correlation as the term is used in stratigraphy. Correlations are of two sorts, pertaining to present or original continuity of lithology, or representing interpretation of contemporaneity; the latter may be of the general time equivalence of units in the same or different depositional areas, or of the synchroneity of depositional surfaces, relative or absolute correlation. The Committee on Stratigraphy, National Research Council, has been publishing exceptionally useful tables of general correlation. The continuity of lithologic units can be demonstrated often, but the precise contemporaneity of horizons in separated sections is rarely established. It has become known that lithic boundaries cross horizons of identical age, but techniques for the recognition of the latter are almost lacking. Classification is a special form of correlation, the probable general equivalence to a unit in a standard section often geographically distant.

Correlations form the foundation for mapping surface and subsurface structures. They present evidence of regional unconformity, bevelling, and overlap. They include determinations of positions in drilling wells so that the character of underlying layers can be anticipated. Correlations are the bases for outlining porous bodies, determining their extent and the nature of their limits; they define the form of rock units, with implications of structural history that may be suggestive. Correlations with near-by basins may suggest developments due to similar or complementing histories. Those made with other provinces may indicate local or regional unconformities, as well as their magnitudes, permitting anticipation of pervious beds toward more complete sections. Classification, correlation to a standard section, is essential to consistent discussion of stratigraphic conditions. Correlation is the essential means by which stratigraphy is formulated. The principles have not changed, but the techniques have advanced.

Lithology in correlation.—Correlation of units in two sections can be demonstrated in simplest form by tracing or "walking out," mapping; aerial photographs have contributed greatly to the accuracy of such work in many areas, and the matching of logs is but an application of the method to subsurface studies. Comparisons may be based on similarity in lithology of one unit in each of two sections; this implies that the rocks were deposited under conditions so similar that methods of study do not permit differentiation, that there is belief in their continuity, or both. Whether they are of the same age depends on whether the conditions progressed in time from one section to the other. Thus the basal unit succeeding an unconformity has probability of continuity, but also of varying age in all but one trend; ordinarily continuity is of greatest practical concern. The distinction between lithologic and time-stratigraphic units has received much discussion. To many geologists, a time-stratigraphic unit is synonymous with a faunal zone.

Determination of precise contemporaneity in separated sections is rarely possible, for few events produced broad, immediate and yet distinctive effects on sediments. Sudden uplift may have spread peculiar and essential synchronous initial detrital sediments over great areas. Rarely, falls of volcanic ash have great utility. Exceptional storms produced intraformational conglomerates, thin shales in off-shore deposits and peculiar primary structures. Possibly earthquakes have caused submarine flow breccias or some clastic dikes. These are but extremes in normal depositional history, the products lithologies that may be more than ordinarily useful in precise correlation.

Probability of correct correlation should be increased if a sequence of similar lithologies is represented in each section. Experience has shown that the seeming greater probability can be misleading when correlation is intended to imply synchroneity, for there are normal progressive lithologic sequences. Thus, there are progressions indicating deepening of water and recession from shore in marine overlap, others showing derivation from rising source lands or those gradually reduced by erosion; most confusing are the many sorts of cyclothems having repetitions even in details. The establishment of correlation between or among sections having contrasting lithologies is commonly established by tracing the intertonguing facies.

Fossils in correlation.—There are inherent advantages in correlation by paleontology that do not pertain to lithology. There has not been such change in processes from early to recent geologic time as to assure determination of age by lithology; conditions have been so similar locally at many times as to form sediments that are relatively identical. On the other hand, there have been progressive changes in the organisms, and the differences can be classified significantly.

The advantages in paleontology decrease as the scale of correlation becomes refined. In classifying units into systems, series or even stages, changes normally are sufficient to permit some assurance of validity. Successive faunas may be so similar in smaller units as to be essentially indistinguishable, and those in restricted areas and lithologies may have greater resemblance to others of different age than to contemporaneous faunas from differ-

ent provinces and habitats. At the smallest scale, variations in populations in synchronous beds are likely to be as great as contrasts in successive beds. Thus paleontology can practically never result in precise correlation of depositional horizons, whereas there is possibility of such correlation in limited areas by lithic criteria.

Correlation by fossils or faunas involves homotaxy, relative identity of forms. Though useful in judging synchrony, homotaxy does not prove it. Relative age is established by superposition in single sections. Forms present in any population represent the influence of the time, but also of habitat reflected in lithology (lithofacies) and of paleogeographic factors controlling migration. Comparisons are commonly made with faunas assembled from several localities; insofar as any faunule deviates in age from another, or the assemblage adds fossils from beds mistakenly correlated, errors are compounded and correlations become less precise.

In early studies, geologists were concerned with classification into the largest categories, systems and series. Correlations were made on the general aspect of the fauna, which usually meant the presence of a few or many genera that seemed significant. As studies progressed with demand for refinement, the preferred correlation of a fauna with one of several in another section on the precentage of common species developed a quasi-mathematical method having an unwarranted impression of validity. The unit is deemed correlative with that in the compared section having the largest percentage of its species. There may be in fact no equivalent, in which case there is, nevertheless, a preferred correlation. Two halves of a single sample may have a low percentage of common forms. The sections compared should be of similar lithofacies, and of biofacies as suggested by the presence of similar organisms. There must be comparable discrimination in the identifications; if the paleontologist tends to separate species on minor differences, he will gain smaller percentage than if he does not. There should be comparable study of successive units in the reference section, and the units should have faunules of similar size. As far as practical, control should be quite continuous. "For establishing the sequence of faunas within a given region, the percentage method is advantageous. It may be useful in affording a clue to proper allocation of a given formation. But in the face of the numerous qualifying factors now recognized, one must conclude that the evidence which the method supplies is relative rather than absolute" (Keen, 1940). Comparing percentages of fossil and recent forms has been a basis for classifying Tertiary rocks since its introduction by Lyell more than a century ago.

Other methods of similar type, such as the correlation of forms in one unit with the median of mid-points of ranges in another, have disadvantages additional to those of the percentage method. The long ranges of some forms may make it impossible to avoid correlation of many units in one section with those near the middle of that compared.

Correlations and classifications are based on one or more of several criteria: (1) the presence of one species or genus that in experience has a limited range; (2) the presence of forms whose upper known range overlaps the lower range of others; (3) sequences of forms or faunas; (4) the presence of an evolutionary stage in a series, a corollary of the preceding; and (5) abundance of forms elsewhere abundant in limited range. The judgment of an expert is on varying consideration of these kinds of evidence.

Fossils most characteristic of a restricted range frequently are known in older and younger beds. Maximum range can never be known, inasmuch as it requires finding the initial and final representatives of the form. Inasmuch as all must have had ancestors, and some, descendents, the range depends on the discrimination. Abrupt changes imply a gap in stratigraphic record in the section, a change in habitat admitting a new biota, or a paleogeographic change allowing introduction of previously foreign elements. There is undue emphasis on absence of forms as evidence of lack of equivalents; most are familiar with inexplicable absence of species in rocks that seem continuous with beds in which they abound. Collections never give the complete fauna, even of durable organisms. Differences

in temperature, salinity, and depth that are not apparent in lithology may have affected the life appreciably. And there are factors of chance and human inadequacy that defy analysis.

The accuracy of correlation depends on the rapidity with which faunas evolved so that the descendent forms are distinguishable, and on the presence of linear descendents in successive strata. Though the discrimination of species be refined, there is probability that the range of variation in ancestor will overlap that in descendent. The initial appearance of derived forms is never exactly known, and ancestral forms persist; frequently there is not progressive and exclusive presence of successive forms, but replacement of older by younger approaching continuous progressive variation and mutation. In a single sedimentary basin having free communication and abundant specimens, correlation may be made fairly confidently on proportions of successive forms, though each will be a probable rather than a precise correlation. Restriction of ingress of forms from locus of origin leads to seeming retardation, with apparent correlation with units older than proper. And if the fossils were differently controlled by ecology, the possibilities of close correlation diminish. Phylogenies rarely are known among fossils that are used as guides in correlation. Thus correlation is based usually not on progressive evolutionary stages, but on forms having scattered places in biological sequence and whose similar ancestors lived elsewhere.

Though one can suggest fields of research that may improve the precision of correlations by fossils, conclusions must remain as among many alternatives. Collection and description continually increase knowledge of forms and their ranges. Thorough studies of large collections are needed, so that range of variations can be established, and comparisons made of synchronous populations. Most descriptions of species are based principally on the holotype, with addition from a few other specimens in a subjective manner; frequently a species is named from very few specimens that fall within the known variation of other named species, though differing from their holotypes. Designations of horizon and locality of types are normally not exact enough to enable further collection of variants; species are type specimens to some and related variant groups to others. Systematic studies between fossils and lithologies are few; such should be particularly informative when applied to rocks whose continuity can be established confidently by other means. There is promising research in the distribution of organisms in modern sediments with respect to lithofacies, and to other conditions of habitat that are not directly evidenced in consolidated sediments. Paleontologists tend to be ill-informed on studies of modern organisms; the Committee on Marine Ecology, as Related to Paleontology, National Research Council, is planning a treatise that should alleviate this shortcoming. The few studies of faunas with respect to their provinces are suggestive.

These and other studies improve the judgment of the significance of fossils. It may be that paleontologic methods have gone about as far as they can in establishing correlations. Quantitative statistical studies of morphological variations seem means of further refinement that rarely have been applied. Exhaustive study and comparison of microfaunas in two wells having excellent samples has been proposed as means of evaluation; similar studies have been made in but few cases of well exposed surface sections.

Correlations will be improved if those who use fossils will be cognizant not only of the possibilities of their methods, but of the limitations. Age is proved only by superposition; identical conditions produce identical deposits, not necessarily laid at the same time, encouraging similar life; ranges are limited by experience, and each case is a possible exception. Relations often are determined by restoration of sections rather than by methods that can be applied empirically.

APPLICATIONS OF CORRELATIONS

Stratigraphic diagrams.—Correlations are but means toward an end, the reconstruc-

tion of the stratigraphy of regions, and determination of its significance. With the establishment of correlation, it becomes possible to interpret the intervening sections, to form restored sections in a vertical plane. These may suggest not only the character of intermediate sections, but the nature of extensions on either end. The directions are only relative, like apparent dips in vertical sections of tilted beds. Thus it is advisable that the relations in three dimensions be gained. Subsurface studies are peculiarly suited to this, for only in areas where structure and erosion expose beds over considerable areas can comparable results be obtained on the surface.

Data can be portrayed in three dimensions by the use of peg models, or the erection of restored sections, preferably on transparent surfaces connecting points where information is known. Such are widely used in mine models, but are not readily reproduced and recorded. Thus information is ordinarily placed on the two dimensions of charts and maps. The effect of three dimensions is gained in drawings comparable to perspective views of models; the projections are normally orthographic, with horizontal distances on the same scale in fore and rear of the diagram. Columnar sections can be erected in proper relative positions, or restored sections constructed to give "fence" diagrams. Maps form a most convenient and informative means of showing the stratigraphy.

Stratigraphic maps.—The past two decades have brought increasing use of maps showing distributions of lithologies, thicknesses of stratigraphic units, and outcrops of formations beneath unconformities. Several papers have summarized the types of maps, and petroleum geologists are quite conscious of their utility. Those based on many attributes of sedimentary particles emphasize directional factors that are significant in interpretation. When prepared on successive horizons, they portray lithologies in three dimensions as a changing picture of the development of the area. There is "increasing realization that the data of quantitative sedimentation are mappable; . . . attribute highs instead of structural highs may afford the magic closed contour for sedimentary-stratigraphic exploration" (Krumbein, 1945). Such projects require much information based on new research. Isopachous maps, showing thicknesses of units in three dimensions, have come into common use in the past decade. Paleogeologic maps present distributions of lithologies beneath overlapping deposits; and there are maps showing limits of successive units above the unconformities.

Inevitably there must be maps showing thicknesses of systems, series and smaller units over large areas of the continent, with complementing paleolithologic and paleogeologic maps; they will be of increasing accuracy and refinement. They can be compiled from maps on larger scale of states or regions, based on uniform or consistent study through their range. This is the present stage; Federal and State surveys and individuals are making very informative contributions. A great deal has been compiled privately; one should not presume that the obvious represents the limit of knowledge and consideration. Inasmuch as every geologist is considerably dependent on publications, release of material that has passed the need of confidence or is on such scale as to lack critical local value will permit better perspective of comparative stratigraphy.

Classification of geosynclines.—The classification of larger rock units on a regional basis is an aspect of stratigraphy that is gaining attention. It is an end, reached after information has been assembled. Classifications of "basins" or "geosynclines," patterns of behavior, encourage critical analysis of the attributes of sediments. Whether or not such deposits are geosynclinal, or are named in one manner or another is not particularly important. Inasmuch as no two deposits are identical, nomenclature might be carried to a ridiculous limit. The endeavor to systematically classify makes for thoughtful discrimination, emphasizes that conditions have changed, that deposits of one age or region have significant similarities and contrasts with those of others, and that there are consistent structural associations.

CONCLUSIONS

This outline of present methods of stratigraphic research has been prepared with the thought that it might suggest studies that would increase the usefulness of stratigraphy in the finding and recovery of oil. Petroleum geologists have been leaders in gaining and recording stratigraphic data, and in applying them to local and regional problems. Each observation adds to the facts on which understanding of earth history is based, and each analysis may lead to recognition of significant principles. The prospects for research are almost limitless. Projects may be formulated to improve some of the techniques, but the greatest gains will come from comprehension of the principles of the science and thoughtful application of known methods of gaining and interpreting information.

ANALYSIS OF SEDIMENTATION AND DIAGENESIS[1]

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INTRODUCTION

In its own area of interest sedimentation concerns both processes and products: the laws of sediment transport as well as the description and interpretation of sedimentary rocks. More broadly, it overlaps the fields of stratigraphy, structure, and reservoir fluids. An analysis of sedimentation centered in its own domain and fanning out toward its borderlands, shows an uneven growth of the subject, here closely pressing its neighbors, there lagging even within its own limits. Problems which await solution range from simple questions of compiling factual data to the development of universal principles of sedimentation. The writer considers all of this work as research, in the sense that even the least of it organizes the scattered facts of the science, and prepares them for more thorough analysis. It may even be argued that a present need is a clearer picture of what the facts really are. However, the mere accumulation of more facts, without establishing a stronger foundation and better framework for interpretation, can hardly be considered an advance in the science. There is little doubt that at present the subject of sedimentation is in a state of flux, with observational data accumulating much more rapidly than present principles can absorb them.

The writer is biased toward the more quantitative aspects of sedimentation, on the ground that numerical data lend themselves better to analysis than qualitative data. Moreover, such numerical data may be mapped with the same precision as any other contour type map, and they may serve as a basis for studying rates of change in sedimentary characteristics, as well as other features which should prove useful in the future search for oil. Ultimately the interpretation of sediments must rest on an understanding of the dynamics of sedimentary processes, and these are in essence expressions of underlying physical and chemical laws. For the study of these laws quantitative data are necessary.

The present treatment is prepared under the auspices of the sub-committee on stratigraphy and sedimentation of the research committee, but the writer assumes responsibility for the form of the analysis. As far as possible the evaluation is slanted toward the usefulness of the subject to petroleum geology, and much of the discussion is in the form of questions rather than statements.

PROCESSES OF SEDIMENTATION

Clastic sediments.—The flow of sediment from source area to final resting place involves a series of physical and chemical changes in the generally heterogeneous weathered

[1] Published with permission of Gulf Research and Development Company.

[2] Gulf Research and Development Company; presently professor of geology at Northwestern University.

debris which forms the initial material. By and large, in its movement from source to point of deposition, the debris is selectively sorted into restricted ranges of size, shape, and density; the soluble portions are carried away; and the clastic particles are worn and abraded during movement. In this truism is contained a host of implications important for the interpretation of ancient sediments. What controls the selective processes? How rapidly do they occur; that is, how far from the source do the effects become apparent? As a stream is followed along its course we find a steep gradient, high velocity, and low discharge near its head, changing gradually to a gentle gradient, low velocity, and large discharge near its mouth. What is the interplay of suspension and traction transport along the stream? What is the relative interplay of selective sorting and abrasion in the several stream sectors? How much uniformity or variability may be expected in the sediments of each sector? Is the changing effect of tributary contributions sufficient in general to eliminate any underlying trends in sediment characteristics along the stream? To what extent may a single large flood upset all this reasoning?

Partial answers can be given to some of these questions, but when parallel problems of winds, waves and currents, ground water, and glacial ice are added to them, the unknown far outweighs the known. Yet underlying all these questions are laws of physics which operate in common among all the agents. The laws of fluid flow play a basic role in the analysis of such phenomena, and serve as an integrating factor among them. To a large extent this domain lies in the borderland between geology and hydrodynamics; the study of fluid turbulence, for example, requires specialized equipment and techniques. However, turbulence is of basic importance in such phenomena as selective sorting, and the distinction between stream and beach deposits, for example, may ultimately rest on distinctions between the turbulence generated in streams and breaking waves.

Non-clastic sediments.—In addition to the physical laws which control the behavior of clastic particles are chemical and biochemical processes which play an important part in the formation of limestone and other non-clastics. Particle size, shape, degree of sorting, and other features of the clastics often remain relatively unchanged among ancient sediments, but the observed textures of limestones may bear little relation to the original size distribution, owing to cementation and recrystallization. Similarly, particle orientation and other features which play a large role in the interpretation of clastic sediments may yield few clues to the conditions of origin of limestones. As far as published literature is concerned, the study of non-clastics has lagged behind that of the clastics, but the importance of limestones as stratigraphic markers, as well as source and reservoir rocks, has given impetus to their study by petroleum geologists. Chemical complexities at the time of origin, as well as ease of post-depositional alteration, raise numerous problems on limestone environments. How close to a shoreline may limestone be formed? Are there factors in original deposition which may predispose porosity in the limestone? What controls the development of oölites, for example, and can the patterns of oölitic occurrence be predicted? The occurrence of biohermal structures in limestones raises several interesting problems. What controls the localization of such bioherms? Can patterns or trends of biohermal development be discerned, and if so, are they predictable? The faunal assemblages in limestones also afford opportunities for studying water depths and other geographic factors of the environment. Much work remains to be done in this overlap region between paleontology and sedimentation.

Environments of sedimentation.—When the study of transportation and deposition advances from single agents to entire environments of sedimentation, problems and questions multiply rapidly. The same environment may include several agents operating concurrently or successively on the same material. Consider a river discharging its load on a beach. Waves and currents rework the material, and as part of the load accumulates along the beach, wind may in turn rework the beach deposits into dunes. Given a sample of dune

sand, how much of the previous history may be read from it? More broadly, if the source of all the beach material is the stream load, to what extent will subsequent processes modify its characteristics, and how rapidly? Can we with certainty trace the gradations from alluvial to beach material in the subsurface?

The environmental interpretation of ancient sediments must begin, in the writer's opinion, with the study of modern environments. It may not be as important to study the environments as exact counterparts of ancient environments, as to study the movement and distribution of sediments over them. Such studies can yield valuable information on the factors which control sedimentary patterns in general. If studies of modern environments are properly oriented, they may be directed toward the solution of many problems of ancient sediments; comparisons may be made, for example, between quiet and agitated conditions; between nearshore and offshore conditions; between brackish and normal marine conditions; and so on. In regional terms it is found that sediments show systematic variations, but in detail there may be many departures and anomalies. To what extent will the pattern of anomalies be characteristic of given environments? Will more rapidly changing conditions give a smaller scale and greater "randomness" to the anomalies? Are there any systematic rates of change of texture, sorting, thickness, permeability, and so on, characteristic of certain environments?

With relatively few exceptions studies of modern sedimentation take too little cognizance of the energy transformations in the environment. It may be possible to discern rates of change of sediment characteristics by observations of the sediments alone, but the complete dynamic picture will not be obtained until the energy is woven into the story. Generally speaking, it is probably true that the most rapid changes in sediment characteristics occur in zones where energy dissipation is greatest or most variable, or both. Turbulence is in essence a powerful energy dissipator; what controls areas of turbulence in sedimentary environments? What are the relations between energy dissipation and mean size, or degree of sorting, or concentration of heavy minerals in the deposit? For that matter, is there any relation between rates of energy dissipation and rates of accumulation of clastic sediments? Between rates of accumulation and permeability, for instance? And so on.

POST-DEPOSITIONAL CHANGES

Diagenetic processes.—Post-depositional changes become significant among fine clastics and non-clastics. Some thirty or more diagenetic processes have been described in the literature, but as yet no comprehensive organization of the subject has been made. The writer suggested that most of the observed changes may be related to half a dozen processes, but details of their exact effects on lithological characteristics are not known. The six processes are compaction, cementation, recrystallization, replacement, differential solution, and the development of authigenic minerals. In addition to these textural and compositional changes are structural changes due to post-depositional slumping and other factors. How soon after deposition do these processes begin? What are the relative rates of the several diagenetic processes in different types of sediment? Most if not all diagenetic problems lie in borderlands between geology and geochemistry and geobiology. The nature of the diagenetic environment in terms of bacterial activity, pH, and redox conditions is being attacked systematically, but questions still far outnumber answers. Among problems of particular interest to petroleum geologists are diagenetic processes which may either increase or decrease porosity and permeability. Under what conditions may original porosity be maintained throughout diagenesis? What sets of conditions may control uniform cementation as against localized "spotty" cementation? Are the patterns of cementation or of diagenetically controlled porosity predictable?

It need hardly be emphasized that petroleum itself owes its origin to diagenetic processes, but the subject is not considered here, inasmuch as it is covered in other committee reports.

Weathering as diagenetic process.—If the definition of diagenesis is broadened sufficiently, it may include weathering changes through which the sediment may pass in later life. Weathering is essentially a process of delithification, but it is much more than a simple reversal of the reactions and processes of lithification. Weathering is in large part a phenomenon of oxidizing environments, whereas diagenesis proper occurs mainly under reducing conditions. The subject of weathering is a science in its own right, and one with which geologists as a group are not too familiar. Of particular importance to geologists, however, is the recognition of ancient soil profiles in the identification of unconformities or intervals of subaerial exposure in rhythms of deposition. What are the criteria by which such ancient soils may be recognized after they themselves are diagenetically altered by burial? Is there a sequence of diagenetic changes in old soil profiles which leaves unequivocal criteria of recognition? Some suggestions may be had from the known characteristics of modern soil profiles. In general the soil-forming process involves desilicification and dealkalization, concurrently with the development of a clay complex. Well developed soil profiles may show variations with depth in their organic content, in the amounts of hydrated aluminum and iron oxides, in the silicic acid content, and in the amount of soluble salts, such as carbonates and sulfates. Some of these characteristics may remain perhaps as concretions in the zone of precipitation, and they could be sought below known unconformities.

PRODUCTS OF SEDIMENTATION

Sedimentary rocks and in some instances their contained fluids are the only products which remain from ancient sedimentary environments, and from them must be read the nature of the environment itself. In general, the process of reconstructing the environment includes a study of the composition, textures, and sedimentary structures of the deposit, as well as the organic remains within it; a consideration of areal extent, lateral variations, and associated beds; and a consideration of contemporary structural control or geographic framework. From the data so assembled a composite picture is constructed, which is compared to what may be expected in corresponding modern environments. All too often the data may be equally well interpreted in several ways, and it is not uncommon to find sediments which cannot even with certainty be identified as marine or non-marine.

Perhaps the greatest single need at present is a set of unequivocal criteria by which ancient sediments may with certainty be identified in terms of their environment of origin. To a large degree this will have to depend upon the recognition of environmental patterns, which requires the study of more than a single sample. Sedimentary environments in all likelihood impress individual patterns upon their deposits, but these patterns may in some instances involve large-scale factors, and in others small-scale factors. In a large epeiric sea it may be expected that the sediments away from shore will be fairly uniform over large areas, so that little lithological difference is noted locally. In more limited environments, especially those in which energy dissipation is irregular in time or space, the scale of variations may be very small, so that correlation even over adjacent wells is difficult. At present, interpretation is limited by an almost complete lack of data regarding the kinds of sedimentary patterns that may be expected under given conditions, or even in many instances a lack of knowledge whether systematic patterns exist. Recourse must ultimately be had to modern environments and to the detailed study of outcrop areas in order to obtain a foundation of fact and theory for interpretation.

Despite present serious gaps in knowledge, interpretation can not await the development of universal principles. Fortunately much can be done with the average single sample, and a nearly complete, although qualitative, picture may be had from a spread of samples. In terms of oil exploration, however, these qualitative pictures suffer from a lack of preciseness. Large areas of potential value can be identified, but prediction of local areas is generally not possible. The oil industry annually spends millions of dollars to obtain precise maps of subsurface structural features, and it will probably have to spend equivalent

amounts to obtain precise sedimentary-stratigraphic maps which can be used in conjunction with other data to make specific well locations on non-structural traps.

Composition of sediments.—The mineralogical composition of sediments has received much attention, inasmuch as classification depends largely on composition. Heavy minerals have been used extensively for correlation and for identifying source rocks or source areas of sediments. Emphasis on quantitative methods in the last two decades has furnished abundant data on relative mineral frequencies, as well as on relative degrees of stability of the several species. More recently emphasis has been shifting from descriptive aspects to the genetic significance of mineral associations in terms of conditions of deposition and contemporary structural controls (as geosynclinal facies as opposed to shallow-platform sea deposits). Aggregate physical properties as porosity have been shown to be related to these genetic conditions, and the field shows much of promise for petroleum geology. As in other aspects of sedimentation, problems which await solution include patterns of mineral variation. What are the rates of change of mineral populations away from the source area? What are the patterns of heavy-mineral distribution in environments, and are they controlled mainly by particle size and density? What effect may weathering have on heavy-mineral associations in regions of low gradient? What is the significance of particular authigenic minerals with respect to the conditions of sedimentation of the deposit, or as indices of the diagenetic history of the deposit? Which minerals are most commonly carriers of the radioactive elements in sediments? Are there any associations of authigenic minerals which can help establish the presence of unconformities or diastems? Associations which may be typical of subaerial weathering or of submarine corrosion come to mind in this connection.

Textures of sediments.—Sedimentary textures include fragmental, crystalline, and oölitic textures. Among fragmental rocks the textures are more closely examined in terms of their particle size, shape, roundness, and surface texture of the grains. Some of these textural elements have been extensively studied, but the subject of surface textures has lagged markedly behind the others. Are any surface textures uniquely associated with conditions of origin? To what extent may post-depositional changes, as differential solution or secondary enlargement, modify original surface textures? What are the relative frequencies of frosted, polished, and other-textured grains in typical modern deposits?

Crystalline textures are typically associated with non-clastics, and may in large part be diagenetic. Secondary growth may be a factor also among clastics. The relation of crystalline textures to porosity and permeability, or to the relative ease with which porous and permeable zones may be developed in them, are important questions in petroleum geology. Oölitic textures have been touched upon previously, and in answer to the question of origin it may be mentioned that current opinion favors agitated nearshore conditions. If that is so, do trends exist in oölitic zones along old shorelines? What is the relation between zones of oölites and biohermal structures?

Among textural details of clastic sediments is the problem of sorting. Degree of sorting plays a role almost as significant as size in controlling permeability. The exact conditions which control sorting are not known, and considerable speculation still exists on degrees of sorting as environmental indices. Probably many kinds of environments locally develop sediments which range from well sorted to poorly sorted. Again it is a question of systematic areal variation, either away from source, or in the direction of decreasing velocities and turbulence. How rapidly does sorting change as one approaches the edge of a sand pinch-out? Can limiting permeabilities be predicted from a knowledge of rates of size and sorting change along sand bodies?

Structure of sediments.—Sedimentary structures include a wide range of features, such as stratification, cross-bedding, ripplemark, concretions, and many others. The origin of particular structures is still largely controversial, and the present state of knowledge appears

to be one in which multiple hypotheses have been advanced, but in which critical data are lacking for narrowing down the possibilities. Bedding and similar features owe their origin to the dynamical conditions in the environment, and are related to degrees of turbulence and strengths of current, which in the final analysis are reflections of energy application or dissipation. The scale of the phenomena, and the persistence or variation of the features horizontally and vertically are important in diagnosing the conditions of origin, and these deserve more study than they have received. Concretions also may have more genetic significance than can be read from them at present. Certain shales have abundant concretions, and it is said that shales rich in organic matter frequently have the most abundant concretions. Whether this is a coincidence, or is related to organic-rich environments, may be worth investigation. Bands of concretions related to ancient soil profiles beneath unconformities also deserve further study.

Mass properties of sediments.—Among mass properties most commonly observed are color, porosity, and permeability. Color is widely used in sediment interpretation, although it is recognized that in many instances it may not be diagnostic. A better understanding of the sequence of chemical environments through which a sediment may pass during and after deposition will do much to shed light on the conditions under which sediments may have distinctive colors. There is a need for a convenient standardized method of describing colors, to facilitate description and comparison of sediments.

Porosity and permeability have been mentioned in several other connections. Of importance in evaluating particular situations is the distinction between primary and secondary porosity and permeability. Some types of primary porosity are quickly lost during diagenesis, whereas other features, such as grain orientation, may predispose the rock to the development of selective secondary porosity. Among limestones these problems become of pressing importance, and the physical and chemical conditions which control the opening or closing of pores in limestones deserve serious attention, as do the factors controlling types of fractures in limestone, and the porosity associated with the several types.

In addition to mass properties commonly observed by geologists is the need for determining other physical properties which play a large part in the newer well-logging devices. The electrical resistivity of various rocks has become important in the interpretation of electric logs, and as geological data are integrated with the logs, the need for such measurements increases. Many of these special properties can be expressed in terms of other sedimentary characteristics, but the prediction of values away from a given well will depend on an understanding of how the several properties vary areally for different types of sediments.

SUMMARY OF NEEDED RESEARCH IN SEDIMENTATION

The many questions raised in the preceding sections serve as a few examples of specific problems which await solution or clarification. These specific problems may be grouped into more general classes of problems, each of which may constitute a major field of research. Emphasis has been placed in the questions on the physical and chemical aspects of the sedimentary problems, and on the systematic variations which may be expected in sedimentary environments. The history of geology is largely a history of increased mapping and the trend toward the mapping of sedimentary attributes is a normal historical development. This mapping is most effective when it is based on measurable attributes, inasmuch as the data are available for applying physical and chemical theory, which are by nature quantitative. This does not mean that qualitative maps are of little value; on the contrary a well prepared qualitative map, by its gradations and shadings, can impart as many suggestions and ideas as a precision map. In the final analysis, however, it will be the precision maps which determine the well locations.

The following list of research projects includes some of the more outstanding oppor-

tunities for systematic attacks which bear a fundamental relation to the further application of sedimentation in oil exploration. Most of the projects are directed toward the discovery of new principles which will aid in sediment interpretation. Some of them are long-time projects and others have a regional significance which may keep them in a competitive status. Many of them require the collaboration of scientists from other fields.

1. A systematic study of one or more present-day environments, including not only the distribution of sediments over the environment, but also the physics and chemistry of the medium, the energy transformations in the environment, and the ecology of the organisms. It would be desirable to choose an area which displays a variety of environmental conditions, such as the Gulf of Mexico, which Lowman elsewhere recommends as a project.

2. A systematic study of selected ancient sedimentary formations from which abundant samples are available, to determine the areal patterns of sediment and faunal variations, as well as the scale-factor in the variations. As with the present-day environment, the study may embrace contrasting types of environment, such as the rapidly changing sections of the Tertiary and the more extensive and uniform conditions of earlier Paleozoic epeiric sea environments.

3. A study of the effects of turbulence and current velocities on mean size, sorting, and bedding structures of sediments. Turbulence includes both an intensity and a scale-factor, either or both of which may vary in different circumstances, as waves and currents. Certain textural features, including even preferred orientation, may be related specifically to the turbulence of winds, running water, and breaking waves by such a study.

4. A study of the chemistry of diagenesis to determine the principle kinds of chemical reactions which occur, in terms of reaction velocities, limiting conditions, and importance in various kinds of sediments or sedimentary environments. Such a study may narrow down the diagnostic value of certain authigenic minerals.

5. A study of the cementation of sandstones, to determine the principles which control local and regional patterns of variation. Such a study would overlap with structural geology, and would afford needed principles for the prediction of tight sands associated with some structures and with some sedimentary-stratigraphic conditions.

6. A study of surface textures of sedimentary particles to determine, experimentally or otherwise, the conditions of solution, of abrasion, and of the deposition of thin surface films, which may develop or modify given surface textures. Such a study will do much to clarify the present use of surface textures as interpretive criteria.[3]

7. An integrated study of sedimentation and paleontology to determine the environmental significance of certain assemblages of fossils, as well as to define the conditions which control systematic variations in faunal content over a given environment.

8. A study of the carbonate rocks, with special reference to syngenetic and diagenetic factors controlling textures, porosity, and permeability. Additional studies on carbonate rocks may include chemical factors controlling dolomitization; and the relations among carbonates and sulphates in evaporite cycles. A broad project on carbonate rocks, embracing these and other features, has been proposed elsewhere by DeFord.[4]

9. The compilation of sets of regional maps showing the paleogeology, paleogeography, thickness, and sedimentary facies of selected systems of rocks. Such a recommendation has been made elsewhere by King, and a complete compilation of this sort would include regional structural features as well.

10. A compilation and critical examination of the numerous criteria which have been proposed for the interpretation of sedimentary rocks. These would include composition, textures, structures, various mass properties, and any others that have been used. The critical testing of these criteria may include comparisons of similar features in recent deposits, as well as an analysis of the physical and chemical conditions which control them.

[3] Since the manuscript was written, the writer has learned that Miss Lou Williams is preparing a Ph.D. dissertation on the subject at the University of Chicago.

[4] This project is now in the process of formulation by a committee headed by W. C. Imbt.

OCEANOGRAPHY AS RELATED TO PETROLEUM GEOLOGY

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GENERAL STATEMENT

Much of the geology of petroleum exploration and development involves detailed determination of past marine environments from examination of the sediments and their contained fossils. From an oceanographic point of view, therefore, studies of marine sediments which can be of the greatest value to petroleum geology should concern themselves with: (1) the principles of their transportation and deposition, (2) the deposition and preservation of their organic content, and (3) the methods of their recognition and correlation, based on their physical characteristics and contained organisms.

If the interpretation of the stratigraphic column could be correlated with a study of similar sediments and similar organic remains being deposited in various Recent marine environments, much useful data might be expected. Relatively little information is available at the present time which can be applied to this problem.

SEDIMENTS AND SEDIMENTATION

If the main contribution of oceanography to petroleum geology lies in a recognition of the environmental conditions responsible for the formation of different classes of marine sediments including possible source and reservoir rocks, the problem must first be approached through a carefully integrated field program. In this report the stress is purposely put on the work at sea rather than on the laboratory investigation of the collected material because the laboratory techniques are fairly well established.

No one branch of oceanography can be completely divorced from the others and although the main emphasis in the problem considered here is on the sediments, it is obvious that biology must be considered in connection with fossils as horizon markers, chemistry as it concerns the nutrients for producing the organic source of oil, and physical oceanography as it concerns the currents and temperature distribution. Furthermore, it is necessary to have a clear understanding of the limitations which working at sea imposes. It is impossible to conduct field work with the same degree of precision with which geological work can be carried out on land, and every cruise carries with it a certain element of chance. A ship and a long string of wire stand between the geologist and his unseen objective.

The coring tube is the most satisfactory device for taking samples of the bottom. The material is brought to the surface relatively undisturbed and it can be taken back to the laboratory in the metal or plastic liner in the same condition. It can also be sealed so that water content can be studied later, as it is rarely practical to conduct any very extensive investigations on shipboard. Cores up to 10 feet are now commonplace with the tubes used at Woods Hole and Scripps, as well as with the more complicated Piggot gun. Ten feet of sediment in deep water represents a considerable period of time because accumulation is relatively slow. Fifteen-foot cores are now entirely practicable, and it is planned to extend the bits to that length in future work at Woods Hole.

A grid of stations, as closely spaced as time and expense will permit, should be laid out over the area to be studied. Probably the shallow-water areas should be more intensively sampled than deep areas because of greater variation in sedimentation. In addition, in a given time more samples can be collected in shallow areas; a deep station may require as much as 2 hours. This grid can be modified somewhat as the work proceeds, but in general it should be followed. Any survey of a relatively unknown marine area is a reconnaissance, and the nature of a sample can never be forecast with certainty.

[1] Woods Hole Oceanographic Institution.

A detailed examination of the sediments collected cannot be made until the material has been brought back to the laboratory. Consequently, regular oceanographic data must be collected on stations spaced frequently enough to give a good coverage of the area being surveyed, if the recent sediments are to be of any value in determining the sedimentary environments of the past.

It is obvious that sediments of high organic content are of considerable interest to this study. During and preceding deposition, oxidation of the organic material must be retarded or prevented if the organic content of the resulting sediment is to be high. This can be accomplished in two ways: either by quick burial, or by deposition in topographic basins, where the water at the bottom is stagnant and oxygen-poor due to lack of circulation. Under these conditions a high rate of productivity of the organisms is desirable, but this is not essential if sufficient time for deposition is allowed. The important thing is that the topographic or sedimentary conditions be such that oxidation is partially prevented prior to deposition and burial. It is also possible that a high organic productivity would in itself cause anaerobic conditions in lower layers of water. For high productivity abundant nutrients, such as phosphates and nitrates, must be present and these, of course, are ultimately derived from the land. Therefore, it would be advantageous to pick a region for investigation where the following conditions exist: abundant nutrients, high productivity, rapid sedimentation, or else a topographic basin or trap. High productivity may occur in either deep or shallow water, in the former case largely in the form of plankton at the surface, in the latter both as plankton and as bottom living organisms. Although there are few quantitative data on the rate of sedimentation, much can be inferred in a qualitative way particularly in shallow water environments. Deep-water sediments, however, should not be ruled out as possible source rocks even though the rate of deposition is presumably slow. With so relatively little information at hand, the study of environments probably should precede that of the processes taking place in recent sediments on the ocean bottom after deposition; and oceanography, therefore, should be mainly concerned at present with the discovery of the sedimentary, physical, and biological environments.

The techniques for studying the material in the laboratory are too well known to discuss here. Studies of organic content might proceed as outlined in Trask and Patnode's book, *Source Beds of Petroleum*. In this connection it might be advisable to sterilize a few samples on board by quick drying, to check against samples that have been allowed to dry slowly. In samples that have been kept wet for considerable periods of time some measureable chemical changes may have been induced by bacterial action. But, on the other hand, it may well be that the differences are unimportant. The physical properties of the sediments may be analyzed by mechanical analysis, water content, liquid and plastic limits tests, and possibly some unconfined compression tests should be applied. These should afford some basis of comparison with the physical characteristics of source and reservoir rocks.

Numerous cores have been taken on the continental slope and near-by ocean basin off the eastern seaboard of the United States by the Woods Hole Oceanographic Institution, and many sedimentary formations have been dredged from the walls of the submarine canyons. These have been analyzed for the physical characteristics of the sediment, and a study has been made of the contained Foraminifera. The data are available for comparison with source and reservoir rocks, or with other recent sediments in any environmental study which might be projected in other regions; but to date the study remains a unit by itself. Most of the data on the physical characteristics and some on the Foraminifera are unpublished as the war interfered with the completion of the report. Studies of organic content have not been made.

R. Dana Russell has taken numerous core and surface samples in the Gulf of Mexico chiefly in the vicinity of the Mississippi Delta, but as far as the writers know the material has never been completely studied because of the war.

Investigations with which the writers are not familiar undoubtedly have been made of near-shore deposits along the Gulf Coast by various oil companies.

Other work in the Atlantic has been deep sea, such as described in the "Meteor" Reports, and shallow-water studies done mainly in connection with European fisheries investigations. Some sedimentary work has been done along the North Sea and Baltic coasts of Germany, and has appeared in the published reports of the various institutes, such as *Senckenberg am Meer* and *Deutsches Seewarte.*

REMAINS OF ORGANISMS USEFUL AS FOSSILS

Fossil organisms are important tools for determining environments of deposition as well as for correlation. For both these problems it is necessary to know as much as possible of the ecology of modern organisms, if we assume that knowledge of past conditions is based on what we know of the present environments. Many of the problems of oil-field exploration and development may be regarded as detailed problems in environmental relationships.

There are several groups of fossils useful in problems of environment and correlation, and there is considerable knowledge of many of the modern counterparts of these groups. Some of these data are of only limited application to paleontology since they were not collected with such an application in mind. Much of the material could be made more useful by being summarized in a form readily available to paleontologists, and the National Research Council Committee on Marine Ecology as Related to Paleontology plans to do this. Most of the modern ecological work has been confined to near-shore and shallow-water areas which are easily accessible. The prevalent idea that most marine rocks were deposited in water not more than 500 or 600 feet may be due to the considerable knowledge of shallow-water biology and relative lack of knowledge of deeper-water forms.

Foraminifera are perhaps the most useful fossils in marine rocks of post-Jurassic age, especially from subsurface samples, but there is very little knowledge of their ecology. There are unpublished studies of foraminiferal depth zones by Lowman and Rolshausen in the Gulf of Mexico and by Cushman and Parker in the Atlantic, and published studies of depth zones off the California coast by Natland and off the Atlantic coast by Phleger. Myers has made population studies of living shallow water benthonic forms, particularly at Plymouth, England, and in the Java Sea. Schott has studied the vertical distribution of living pelagic forms in the South Atlantic, and Phleger has made experimental quantitative plankton tows for living Foraminifera in the North Atlantic.

The investigations here indicated represent only the smallest beginning on problems of foraminiferal ecology. A reasonable general program of research in this field might be listed as follows.

1. There should be a systematic collection of a large number of undisturbed bottom samples from all types of environments and all depths of water. There should be population studies of the living benthonic Foraminifera, and their distributions, related to temperature, depth, chemical constitution of the water, character of the bottom, and distribution of the general biota. In addition, the distribution of empty tests of benthonic Foraminifera should be studied and compared with the distribution of living forms.

2. Quantitative plankton tows should be taken seasonally from various environments and from all depths for geographic and bathymetric distribution of pelagic Foraminifera. These data should be related to features of the physical and biologic environment. The accumulation of tests of Foraminifera in bottom sediments should be compared with their distribution and productivity in the plankton.

3. Vertical distribution of pelagic and benthonic Foraminifera should be studied from submarine cores, taken from all kinds of environments.

The necessity for rather complete oceanographic data in connection with any investigations of this type must be stressed. Distribution of temperature, salinity, oxygen, nitrates,

phosphates, calcium carbonate, and currents represent, to the oceanographer, rather obvious features for study. Any sediment is composed of inorganic and organic constitutents which are in part the result of the environment under which it accumulates; and this environment includes all the features of the entire water column above it and from adjacent areas.

The following are the only investigations known to the writers which are neither underway at the present time or definitely planned for the near future. There may be other studies which are not enumerated here.

1. It is understood that Cushman and a collaborator are finishing the description of shallow-water faunas from the southern Atlantic continental shelf.

2. The following work on Foraminifera is underway or planned at the Woods Hole Oceanographic Institution.

a. A review of the geographic and bathymetric range of the more common calcareous Foraminifera, from published sources, is in the process of being completed.
b. A detailed survey of the sediments and Foraminifera of the Gulf of Maine has been started.
c. A cooperative project has been discussed with members of this subcommittee of the A.A.P.G. for an investigation of the sediments and Foraminifera of the Gulf of Mexico. Prior to the commencement of any such extensive undertaking the Woods Hole Oceanographic Institution will conduct a reconnaissance of the deeper-water sediments, beyond the continental shelf, in this region.

This is being jointly financed by the Geological Society of America and the Woods Hole Oceanographic Institution.

SUBMARINE GEOLOGY STUDIES IN THE PACIFIC

FRANCIS P. SHEPARD[1]
La Jolla, California

Information on submarine geology comes from various sectors of the Pacific. The earliest marine investigations in which geology played an important role were those of the "Snellius" in the Dutch East Indies. Geological results of the Snellius Expedition have appeared in three parts, the last of which, pertaining to the bottom samples should be of especial interest to stratigraphers and to petroleum geologists in general. The Scripps Institution embarked on a major program of submarine geological investigations in 1937. This program has continued up to the present, being considerably accelerated by requirements of the Navy during the war. Most of the investigations have been made along the coasts of southern California and Lower California and in the Gulf of California. However, during the war investigations covered all portions of the Pacific where there were naval activities.

The work at Scripps Institution and at the Point Loma Navy Radio and Sound Laboratory has resulted in the acquisition of thousands of bottom samples, mostly from shallow depths, the obtaining of numerous bottom-current readings, the taking of many bottom photographs, the determination of the nature of movement of sands along the shores, and the construction of numerous bottom-sediment charts of the continental shelves around the Pacific. At the present time only a small portion of the information gathered from these studies has been published. Reports from other portions have been submitted and others are in process of preparation. A book on "Submarine Geology" which will make a survey of all of available recent information is now nearing completion. The present status of the investigations and suggestions for future investigations will be given in the account to follow.

[1] Scripps Institution of Oceanography.

I. The subjects which have been moderately well covered by past studies include the following.

1. The character of the submarine canyons off the California coast, including topography, bottom character, currents on the bottom, and slumping of materials on the floors and walls of the canyons.

2. The nature of the banks and seamounts off the California coast investigated by dredge hauls of rocks, and sediment collections and a few submarine photographs.

II. Other subjects concerning which we have considerable information most of which has not yet been published include the following.

1. The topography of the Gulf of California (submitted for publication) which includes information on submarine fault scarps and fault troughs.

2. The sediments of the shelves, troughs, and basins off California and in the Gulf of California. Thousands of samples have been collected and about half of them have been analyzed. The need of having this work completed is one of our most pressing problems. It has been held up by the war in that Roger Revelle, our sedimentationist, has been in service, but on the other hand, our war activities have led to the collection of several thousand samples most of which have been analyzed. Cuts from some of these samples probably can be obtained for special studies by application to K. O. Emery at the University of Southern California.

3. The distribution of the sediments on the continental shelves off eastern and southeastern Asia and off most of western United States. This was determined from chart notations for the benefit of the Navy. Two of these charts were put on exhibit at the 1945 meetings of the Geological Society of America. All of this information is now released for publication. A large amount of information regarding sedimentation will become available by this release although the information is, of course, inaccurate since it depends on the ability of the surveyors in interpreting the sediments which they obtained in the tallow cups of their leads or in their small snappers. Despite such shortcomings it should be of value, particularly in directing future sea-floor investigations to areas of special interest.

4. Studies of the beaches of California in relation to sources of material, seasonal evolution, fate of sediment removed by winter storms, nature of the processes which replenish the sand during high waves, and the nature of long-shore drifting and diffusion. This work had been started before the war and some publications have been issued, but investigations on a larger scale were initiated as a result of a demand for information on landing beaches on which much attention was focused in the spring and summer of 1945. Despite the end of the war the beaches are still being investigated and a large amount of new information will be forthcoming.

III. Investigations which are needed and which are not definitely included in the present program at Scripps Institution include the following.

1. Extensive coring in the troughs and basins off southern California, Lower California and in the Gulf of California. The purpose of this work would be to obtain better material for correlation with the basin deposits associated with California oil fields. There is much evidence that some of the Pliocene formations were deposited in similar deep environments.

2. Coring of the deep oceans. This work may yield evidence of climatic changes and possibly of sea-level changes in the Pleistocene and even in the Pliocene. Only one long core is now available from the deep Pacific.

3. Drilling into the coral atolls and collection of samples from the slopes around atolls at various depths. This work may throw light on the recent history of the oceans and will certainly be instructive in regard to the origin of limestone and dolomite. There is some evidence to show that the materials underlying atolls are calcareous to considerable depths, but that dolomite increases with depth. Also coral structures appear to change into dolo-

mitic non-coralline limestones with depth. The recent work at Bikini may have eliminated the necessity of some of this work.

4. Submarine photography to supplement the small number of photographs now available from various depositional and nondepositional environments off the California coast. The photographs will reveal such things as ripple marks, smoothness of depositional surfaces, abundance and nature of organisms on the bottom, nature of rocky surfaces, and many other features which may be of interest to stratigraphers.

PROGRESS OF STUDIES RELATING TO MICROBIOLOGY OF SEDIMENTS

CLAUDE E. ZoBELL[1]
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Recent sediments, both marine and lacustrine, contain large numbers of biochemically active bacteria and allied microorganisms at the greatest depths from which samples have been carefully examined. These microbes are believed to influence physico-chemical conditions, the transformation of organic matter and the diagenesis of sediments in various ways. In fact, bacteria appear to be the principal catalyzers of chemical and physico-chemical reactions in recently deposited sediments.

Some of the properties of recent sediments which are known to be affected by microbial activity are oxygen tension, oxidation-reduction potential, hydrogen-ion concentration, carbonate (limestone, *et cetera*) content, quality and quantity of organic matter, particle aggregation, state of iron and manganese, sulphide and sulphate content, animal population (protozoa, worms, burrowing animals, *et cetera*), and surface tension. With few exceptions our information on these matters is only qualitative. Quantitative data would contribute much to our knowledge of sediments and the processes of sedimentation and the diagenesis of sediments.

Most urgently needed is information on the effect of microbial activity on the organic content of sediments. This subject should be studied stratigraphically in long cores of rigorously collected sediments. Comprehensive studies of the organic constituents of sediments and of the bacterial activity in these sediments collected from different depths from selected depositional basins should give information on the beginning of petroleum genesis and on diagenetic processes in general. Distribution patterns of organic constituents and microbiological processes may prove to be of considerable assistance to oil geologists in their interpretations of the conditions under which oil-bearing horizons have been formed and may be found. Closely related studies are now in progress as part of A.P.I. Research Project 43A, which is concerned with the "Role of Microorganisms in the Formation of Petroleum," but the problem merits much more intensive and extensive attention. The problem could be studied as a new project without overlapping or duplicating the work of Project 43A.

Another problem of considerable importance is the redox potential of sedimentary material. Preliminary observations indicate that the redox potential has a pronounced effect upon the composition, chemical reactivity, diagenesis, color, biological population and other properties of recent sediments and upon the formation and preservation of petroleum. Highly reducing conditions favor biochemical hydrogenation or the reduction of organic matter, processes which tend to convert organic matter into petroleum hydrocarbons. It has been postulated that it is primarily the redox potential which determines whether organic matter in sediments is converted into coal or petroleum. Since petroleum

[1] Scripps Institution of Oceanography.

seems to occur only in highly reducing environments, it is believed that the redox potential may prove to be a significant characteristic of source sediments. This subject is presented by a microbiologist because bacteria appear to be the principal dynamic agents which are responsible for the redox potential of recent marine sediments. This problem is receiving some attention as a part of A. P. I. Research Project 43A, but provisions have not been made for giving the problem anything like the concentrated attention that its importance seems to warrant.

The writer is working on a monograph tenatively entitled, "Geomicrobiology," or the role of bacteria as earth agents. Chapter headings include the following topics: Soil Formation, Diagenesis of Sedimentary Deposits, Microbiology of Peat and Coal, Petroleum Genesis, Hydrocarbon Oxidation, and Sulphur Transformation, each topic being treated from the microbiological point of view. If suitable arrangements can be made, including sponsorship of the project, full time may be devoted to the project next year on sabbatical leave.

With the exception of the work which is being done here, the writer is aware of no sustained studies on the microbiology of sediments, although several laboratories are working sporadically on the subject. Further information may be obtained from the following publications by the writer.

"Changes Produced by Microorganisms in Sediments after Deposition," *Jour. Sed. Petrol.*, Vol. 12 (December, 1942), pp. 127–36.

"Studies on Redox Potential of Marine Sediments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 4 (April, 1946), pp. 477–513.

"Influence of Bacterial Activity on Source Sediments," *Oil Weekly*, Vol. 109 (April 26, 1943), pp. 15–26.

"Occurrence and Activity of Bacteria in Marine Sediments," *Recent Marine Sediments*, Amer. Assoc. Petrol. Geol. (1939), pp. 416–27.

"Activities of Microorganisms in Bottom Deposits," *Marine Microbiology*. Chronica Botanica Publishing Company, Waltham, Massachusetts (1945).

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

RECENT PUBLICATIONS

ALBERTA

*"Structure at Depth on the Plains of Alberta," by Ralph L. Rutherford. *Trans. Canadian Inst. Min. Met.*, Vol. 49 (1946), pp. 191–98; 2 figs., 1 table.

COLORADO

*"Looking at Rangely from the Bottom——Up!" by S. M. Newton. *Oil Reporter*, Vol. 3, No. 20 (Denver, November 19, 1946), pp. 8–9, 18–24; illus.

GENERAL

"Notes on Flow-Time Effects in the Great Artesian Aquifers of the Earth," by P. Wilh. Werner. *Trans. Amer. Geophysical Union*, Vol. 27, No. 5 (October, 1946), pp. 687–708.

*"Bibliography of Seismology, Items 6,047–6,142, January to June, 1946," by Ernest A. Hodgson. *Pub. Dominion Observatory*, Vol. 13, No. 19 (Dept. Mines and Resources, Ottawa, Canada, 1946), pp. 317–29. Price, $0.25.

*"Photogeology Aids Oil Exploration," by Laurence Brundall. *Oil Weekly*, Vol. 124, No. 1 (Houston, December 2, 1946), pp. 18–23; 1 fig., 5 aerial photographs.

Identification and Qualitative Chemical Analysis of Minerals, by Orsino C. Smith. 386 pp., illustrated in full color. Handbook covering 2,000 minerals. 6×9 inches, cloth. Published by D. Van Nostrand Company, Inc., New York City (1946). Price, $6.50.

"Geological Survey's Studies and Potential Reserves of Natural Gas," by H. D. Miser. *U. S. Geol. Survey Cir. 14* (1946). 20 pp. Reprint of paper delivered at hearing of Federal Power Commission, June 19, 1946. Free on application to Director, Geological Survey, Washington 25, D. C.

Oil Across the World, by Charles M. Wilson. 318 pp., illus. Evolution of the pipeline and its part in the growth of the petroleum industry. Longmans, Green and Company, New York City (1946). Price, $3.50.

*"The Future of Wildcatting," by J. V. Howell. *Independent Petrol. Assoc. America Monthly*, Vol. 17, No. 7 (Tulsa, November, 1946), pp. 24–26, 37; 1 table. Earlier efforts to forecast the future of oil are reviewed and potential oil provinces outlined.

ILLINOIS

"Pennsylvanian Ostracodes of Illinois," by Chalmer L. Cooper. *Illinois State Geol. Survey Bull. 70* (Urbana, November, 1946). 177 pp., 21 pls., 38 figs., faunal chart. Mail orders should be sent to State Geological Survey, Urbana, Illinois. Price, $1.00; postage, $0.07.

ITALY

*"Italy's Production Program Lies Ahead," by J. Brian Eby. *Oil Weekly*, Vol. 124, No. 1 (Houston, December 2, 1946), International Section, pp. 3–6; 1 fig., 3 tables, 3 photographs.

NEW MEXICO

"Geologic Map and Stratigraphic Sections of Paleozoic Rocks of Joyita Hills, Los Piños Mountains, and Northern Chupadera Mesa, Valencia, Torrance, and Socorro

Counties, New Mexico," by R. H. Wilpolt, A. J. MacAlpin, R. L. Bates, and Georges Vorbe. *U. S. Geol. Survey Prelim. Map 61*, Oil and Gas Investig. Ser. (December, 1946). Single sheet, 44×64 inches. Scale, 1 inch equals 1 mile. Stratigraphic sections; scale, 1 inch equals 200 feet. Printed in green and black. Index map and brief text describing the geology and oil and gas possibilities, including possible stratigraphic traps, are printed on same sheet. Mail orders should be sent to Director, Geological Survey, Washington 25, D. C. Price, $0.65.

OKLAHOMA

"The Lower Permian and Upper Pennsylvanian of North-Central Oklahoma." Guidebook of the Oklahoma City Geological Society field trip, November 14 and 15, 1946. 17 pp., 13 pls., available from Secretary, Oklahoma City Geological Society, 965 First National Building, Oklahoma City 2, Oklahoma. Price, $2.00.

QUEBEC

*"Canada's Gaspé Peninsula——Its Petroleum Possibilities," by Fred W. Bates and Robert R. Copeland, Jr. *Oil Weekly*, Vol. 124, No. 1 (Houston, December 2, 1946), International Section, pp. 17–24; illus.

ROUMANIA

*"La Prospection pendant la Guerre et ses Prospectives d'Avenir (Prospecting during the War and Its Future Outlook)," by A. Voronca. *Monitorul Petrolului Român*, Nos. 7-8-9 (Bucharest, Roumania, July-August-September, 1946), pp. 232–34; 1 fig., 1 table. Summary of world-wide geophysical exploration for oil during 1941–1945, and prospect of continued activity. Based largely on reports published in the United States in 1946. In French.

TEXAS

*"Texas Mineral Resources." *Univ. Texas Bur. Econ. Geol. Pub. 4301* (Austin, January 1, 1946). 390 pp., 28 pls., 88 figs. 27 papers by various authors describing specific mineral deposits in Texas or dealing with subjects of interest in connection with the development of mineral resources.

URUGUAY

*"Mapa Geologico de la Republica Oriental del Uruguay (Geological Map of the Eastern Republic of Uruguay)." A new edition, revised and drafted by the Section on Economic Geology of the Geological Institute of Uruguay, Eduaido Terra Arocena, director, with the collaboration of Nicolás Serra, Juan H. Caorsi, and Ruben Bonfiglio. Size, 33×41 inches. Scale, 1:750,000. Engraved in colors. Issued by the Ministry of Industry and Labor on the occasion of the Second Pan-American Congress of Mining Engineers and Geologists, held in Rio de Janeiro, Brazil, in October, 1946.

U.S.S.R.

*"On the Principal Structural Elements and Possible Future Oil and Gas Resources of the Southern Border of the European Part of the USSR," by I. O. Brod. *Comptes Rendus (Doklady) de l'Académie des Sciences de l'URSS*, Nouvelle Série, Vol. 49, No. 7 (Édition de l'Academie des Sciences de l'URSS, Moscou, 1945), pp. 510–13; 1 structural map of the southern border of the European part of the USSR. In English.

UTAH

"Late Mesozoic and Early Cenozoic History of Central Utah," by E. M. Spieker. *U. S. Geol. Survey Prof. Paper 205-D* (September, 1946), pp. i–iii, 117–61; pls. 18–25, Figs.

14–21. For sale by Superintendent of Documents, Government Printing Office, Washington 25, D. C. Price, $0.15.

WYOMING

"Tertiary Stratigraphy in the Northeastern Part of the Wind River Basin, Wyoming," by H. A. Tourtelot and H. L. Nace. *U. S. Geol. Survey Prelim. Chart 22*, Oil and Gas Investig. Ser. (September, 1946). Single sheet, 40×52 inches. Mail orders should be sent to Director, Geological Survey, Washington 25, D. C. Price, $0.40.

DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 20, No. 6 (November, 1946)
"Corals from a Lower Pliocene Patch Reef in Central Java," by J. H. F. Umbgrove
"Middle Mesozoic Nonmarine Ostracodes," by F. M. Swain
"Middle Permian Cephalopoda from Texas and New Mexico," by R. L. Clifton
"Three New Foraminifera from the Tertiary of Ecuador," by Robert M. Stainforth and Frank V. Stevenson
"A Carapace of the Ordovician Trilobite *Telephus*," by Alfred G. Fischer
"Arenaceous Foraminifera and Lagenidae from the Neocomian (Lower Cretaceous) of the Netherlands," by A. ten Dam
"A Cambrian Ostracode from Oklahoma," by Edward A. Frederickson
"The Conodont Fauna of the Ordovician Dutchtown Formation of Missouri," by Walter Youngquist and James S. Cullison
"Bibliography of Foraminifera for the Year 1945 (with Supplements for the Period 1936–1944)," by Hans E. Thalmann
"*Alaskoceras* and the Plectoceratidae," by Rousseau H. Flower

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 16, No. 3 (December, 1946)
"Comparative Rates of Weathering of Some Common Heavy Minerals," by Lincoln Dryden and Clarissa Dryden
"Suspended Sediment Program of the Rock Island Office, Corps of Engineers, U. S. Army," by Troy L. Péwé
"The Correlation of Sedimentary Rocks by Fossil Spores and Pollen," by L. R. Wilson
"Sediments from Alaskite, Capitan Mountain, New Mexico," by Raymond Sidwell
"A Color-Numerical System as Applied to Well Logs," by D. C. Maddox

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REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL: PHILIP B. KING (1949)

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PAUL WEAVER (1948), *vice-chairman*, Gulf Oil Corporation, Box 2100, Houston, Texas

1947	1948	1949
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1947	1948	1949
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JOHN L. FERGUSON	CARROLL M. WAGNER	
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MAX W. BALL, *chairman*, Denver National Bank Building, Denver, Colorado

A. C. BACE	DON L. CARROLL

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

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Rufus M. Smith, Richard B. Rutledge, E. O. Markham
Edward Willard Berry, Durham, N. C.
K. D. White, W. B. Spangler, Joseph T. Singewald, Jr.
Bland David Bounds, Evansville, Ind.
D. E. Lounsbery, Homer H. Charles, Oscar M. Hudson
William Jarrott Harkey, Dallas, Tex.
Lorenz Shock, L. F. Uhrig, Leo R. Newfarmer
Charles Rene Houssiere, Jr., Lake Charles, La.
George S. Buchanan, George I. McFerron, W. R. Canada
Charles Spurlin Johnson, Houston, Tex.
A. A. Hunzicker, Joseph H. Markley, Jr., Louis A. Scholl, Jr.
Ralph Eugene McMillen, Caracas, Venezuela, S. A.
Hollis D. Hedberg, J. M. Patterson, M. Kamen Kaye
Percy Lee Prout, Mt. Pleasant, Mich.
William M. Schulz, William F. Brown, Glenn C. Sleight
John Rodgers, New Haven, Conn.
Hugh D. Miser, Chester R. Longwell, Philip B. King
Vernon Zay Smith, Denver, Colo.
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John Wentworth Sullivan, Corpus Christi, Tex.
Carl W. Hubman, W. E. Greenman, Dale L. Benson

FOR ASSOCIATE MEMBERSHIP

Charles Chester Clark, Rawlins, Wyo.
W. D. Frazell, W. H. Marshall, A. C. Wright
Paris Maurene Gaddy, Austin, Tex.
Fred M. Bullard, Don L. Frizzell, Hal P. Bybee
Charles William Muil, Kingsville, Tex.
S. A. Lynch, Frederick A. Burt, Harold Vance
Roderick Goldston Murchison, Jr., Monteria, Bolivar, Colombia, S. A.
Philip Andrews, J. A. Tong, A. D. Graves
Richard Cox Northup, Socorro, N. Mex.
Robert L. Bates, Ralph H. Wilpolt, Georges Vorbe
Hylda Merle Rabel, San Antonio, Tex.
Harold G. Picklesimer, James K. Rogers, Worth W. McDonald
William Adams Riggs, Wilmington, N. C.
Garland Feyton, Victor Cotner, F. Stearns MacNeil
Joseph Franklin Rominger, Long Beach, Calif.
Donald C. Duncan, Ian Campbell, Edward C. Dapples
Warren Edson Tomlinson, Wichita, Kan.
S. A. Thompson, William W. Clawson, E. P. Philbrick

John Clifton Tyler, Jr., Houston, Tex.
Lloyd M. Pyeatt, Fred L. Smith, Jr., W. F. Cooke, Jr.
Robert Carel van Bellen, Haifa, Palestine
Hans E. Thalmann, D. J. Doeglas, H. M. E. Schurmann
John Stephen Wonfor, Westmount, Quebec, Canada
V. E. Monnett, C. E. Decker, G. S. Hume

FOR TRANSFER TO ACTIVE MEMBERSHIP

Donald Arthur Gray, Wichita Falls, Tex.
F. H. Schouten, J. J. Maucini, William Lloyd Haseltine
Frederick Thompson Holden, Shreveport, La.
Robert W. Beck, E. B. Hutson, James W. Hunter
John Taylor Sinclair, Jr., Caracas, Venezuela, S. A.
John F. Dodge, G. C. Pfeffer, Florent H. Bailly

JOINT ANNUAL MEETING, BILTMORE HOTEL, LOS ANGELES, MARCH 24–27

HAROLD W. HOOTS[1]
Los Angeles, California

American Association of Petroleum Geologists

Executive Committee

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Convention Arrangements

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Howard C. Pyle, General Vice-Chairman

Committee Chairmen

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Frank A. Morgan Reception	E. R. Atwill Entertainment	Gordon Bell Publicity	W. P. Winham Exhibits
John C. Hazzard Field Trips	H. J. Steiny Transportation	Herschel Driver S.E.P.M.	Eugene H. Vallat
			Henry Salvatori S.E.G.

[1] General chairman, convention arrangements.

ANNOUNCEMENT

The 32d annual meeting of the American Association of Petroleum Geologists will be held at the Biltmore Hotel, Los Angeles, California, on March 24–27, 1947. The 17th annual meeting of the Society of Exploration Geophysicists will be held on March 25–27, and the 21st annual meeting of the Society of Economic Paleontologists and Mineralogists, will be held on March 26 and 27. A cordial invitation is extended by the Pacific Section to all Association and Society members and their wives.

ATTENTION PLEASE

Information from returned post-cards as to certain and probable attendance at the Los Angeles convention in March, 1947, indicates an unusually large attendance for a California meeting—50–100 per cent larger than in 1937. This is gratifying to your executive committee, your convention committee, the Pacific Section, and particularly to the tough and hard "Old Guard" members of the Association. Such attendance will demonstrate clearly to these groups that you consider these annual conventions worth-while, that you like to come to one held in California, and that our membership is still composed of hardy men who, when in quest of additional knowledge, will knowingly subject themselves to almost any hardship—and return home with a grin.

Ten years ago—back there in 1937—the Biltmore Hotel urged us to take full advantage of their 1,500 rooms to house our visiting members and guests, and to accept *gratis* all space needed for technical sessions, committee meetings, and exhibits. Those were the days when California was called the land of free milk and honey. To-day, after much maneuvering on both sides, the Biltmore allows us a total of 250 rooms for an anticipated attendance of 1,500–1,800 and charges us $1,500 for the meeting rooms essential to our convention. Since the Biltmore will be housing only one out of every four or five person attending the convention, all responsibility for your reservation, assigning you to a hotel, obtaining the required advance deposit, and confirming your reservation must be handled by our hotel and housing committee. This local committee is eager to do a good job. Its one big hope is that the 75–80 per cent of attending members and guests who do not obtain reservations at the Biltmore Hotel will be those hardy folk with the characteristic grin. California members needing reservations will be assigned to hotels other than the Biltmore.

An excellent technical program, instructive field trips, and plenty of opportunity for entertainment will combine to make this a good meeting.

A modest registration fee will be charged to assist in defraying the costs of this convention.

TECHNICAL PROGRAM

The technical program is designed to present and explore problems encountered by those engaged in petroleum exploration in lands adjacent to the Pacific Ocean. It will be initiated Monday evening with a discussion of sedimentation in the small, deep basins such as are found on the Pacific Coast. Manley Natland will describe a condition in the Los Angeles Basin in which deep-water fauna are found at the edge of deposition in the Puente sea. This paper is to be followed by K. O. Emery's discussion of "Patterns of Sedimentation on the Continental Shelf off California." This theme will be pursued further on Tuesday afternoon by a series of papers on California in which Harold W. Hoots will first picture the general geological situation and its relation to the development of the petroleum industry. Then there will be three papers on the genesis and evolution throughout Tertiary time of "The Los Angeles Basin" by Herschel Driver; "The Ventura Basin" by Thomas L. Bailey; and "The Great Interior Valley" by Glenn H. Ferguson.

The Tuesday morning session will provide the formalities of the opening of the annual meeting, including the presidential addresses and various awards. Two important papers

will also be presented at this session. K. C. Heald will give a running account of the highlights of domestic developments in 1946 and L. G. Weeks will treat foreign developments in the same manner. The geophysicists will hold a separate technical session in the afternoon. A paper on "The Petroliferous Provinces of Washington and Oregon" will wind up the day's program.

Wednesday will be devoted to discussions of the geology of lands bordering the Pacific. Professor Walter H. Bucher will set the stage for this with his discussion of the "Geologic Framework of the Pacific." This will be followed by papers on China by Carlton D. Hulin; The Philippines by Grant W. Corby; Japan by Charles W. Chesterman; Petroleum Production and Resources of Japan by David Cerkel and J. L. Williams; New Zealand by Frank Turner; Central America by Wendell P. Woodring; Eastern Peru and Ecuador by Bernhard Kummel; Coastal Oil Fields of Peru by A. Lyndon Bell; and Chile by Glen M. Ruby. A paper by L. G. Weeks, entitled "Paleogeographies of South America," will be on the Wednesday program. The geophysicists are planning no separate technical session on Wednesday but are providing two and possibly three papers to be presented Wednesday morning at the combined session. These will be of equal interest to geologists and geophysicists. One of them is "Geophysical Work in the East Indies" by O. F. Van Beveren. The paleontologists will hold separate technical sessions in both morning and afternoon.

Overthrusting is a condition met very frequently and in widely separated areas by geologists in Pacific regions. Wednesday evening is to be dedicated to this problem. Theodore A. Link will guide the symposium and lead off with a discussion of overthrusting in Alberta. Edward C. H. Lammers will discuss overthrusting along the Santa Clara Valley in California where many oil fields exist both above and below the thrust planes, and Donald LeRoy Blackstone, Jr., will discuss overthrusting in Rocky Mountain petroliferous provinces.

Thursday will be devoted to domestic, descriptive, and development papers. Already a number of these have been arranged through the aid of the publications committee with its widespread membership and their resultant familiarity with interesting developments and the men best qualified to present them. There will be a variety of papers from Texas, Louisiana, Florida, Oklahoma, New Mexico, the Rocky Mountain states, and others. The paleontologists will hold a symposium on "Sedimentary Lithology" in the morning, and the geophysicists will hold technical sessions all day Thursday.

GENERAL OUTLINE OF PROGRAM

Sunday, March 23	A.A.P.G. Research Committee meeting.
Monday, March 24	Joint Registration and Committee Meetings.
Night.	Open Session. Tertiary and Recent Sedimentation, a Symposium.
Tuesday, March 25	
A.M.	Joint Session. Presidential addresses and awards; Reviews.
P.M.	A.A.P.G. California petroliferous basins.
P.M.	S.E.G. Business Meeting and technical session.
Wednesday, March 26	
A.M.	Joint Session. Geology of foreign lands bordering Pacific.
	A.A.P.G. Business Meeting
	S.E.P.M.—A.M. California stratigraphy.
	P.M. General Paleontology.
Night.	Open Session. Thrust Faulting Symposium.
Thursday, March 27	
	A.A.P.G. Geology and development papers Mid-Continent, Gulf Coast Rocky Mountains.
	S.E.P.M.—A.M. Symposium on sedimentary lithology.
	S.E.G. Technical sessions.
Night.	Dinner-dance.

FIELD TRIPS

1. Chester Stock, of the California Institute of Technology, will conduct a field trip to the La Brea Fossil Pits and the Los Angeles Museum on the afternoon of Monday, March 24.

2. The Society of Exploration Geophysicists is planning a trip to the California Institute of Technology and its Seismological Laboratory in Pasadena on the afternoon of Wednesday, March 26.

3. A post-convention field trip is scheduled to leave 9 A.M., Friday, March 28, returning to Los Angeles late Sunday afternoon, March 30. The first day will cover structural and stratigraphic features of the Aliso Canyon field, the Santa Clara Valley, and the Ventura Avenue field. Those desiring to return to Los Angeles at the end of the first day's tour may do so from Ventura.

Friday night will be spent at Santa Maria. Saturday morning the Santa Maria area will be studied and in the afternoon the party will leave for Bakersfield *via* the Cuyama Valley; the San Andreas rift and the Midway-Sunset district will be viewed *en route*. Saturday night will be spent at Bakersfield. On Sunday, fields of the west side and central part of the southern San Joaquin Valley will be visited and the return trip to Los Angeles will be made *via* the Ridge Route.

Transportation costs for the three-day trip will be prorated and paid by each person attending. In view of transportation requirements and the limited hotel accommodations in both Santa Maria and Bakersfield it is absolutely essential that firm reservations be made by those planning on this trip. Those interested in this post-convention field trip should not fail to indicate their wishes on the reservation form to be mailed them for that purpose.

EXHIBITS

Desirable advertising space for exhibits of equipment, maps, and services used in petroleum exploration is available in the Foyer, at the entrance to the technical meetings. Parties interested in purchasing space and arranging for exhibits should write immediately to W. P. Winham, 605 West Olympic Boulevard, Los Angeles, California.

ENTERTAINMENT

The dinner-dance in the Biltmore Bowl on Thursday night and the ladies tea on Tuesday afternoon constitute the only planned entertainment on the program.

Tuesday night, with no technical meeting, is available for those who wish to plan entertainment. Those desiring assistance in obtaining reservations for The Drunkard (lots of fun) for Tuesday night, or for Earl Carroll's Night Club or the Cocoanut Grove (Ambassador Hotel) for Tuesday or other nights, should so indicate on the enclosed reservation form

LADIES ENTERTAINMENT

Entertainment for visiting ladies is being planned by a local group under the leadership of Mrs. Carroll M. Wagner. A tea, sponsored by Mrs. Earl B. Noble, will be held at the Avila Adobe in Calle Olvera at 3:00–5:30 Tuesday afternoon, March 25. All ladies are cordially invited. The Avila Adobe is the oldest house in Los Angeles and one of the historic spots of Southern California. Its setting in the midst of old Spanish Los Angeles will be pleasing to those who still can imagine being stirred to romance by Spanish music and a gay Caballero.

Other entertainment for ladies will be provided in accordance with existing facilities and the indicated wishes of those who plan to attend. Herewith is a list of events which,

according to present tentative plans, will be available within limits. The indication of your wishes on the reservation form which is to be mailed you will necessarily constitute a reservation, and will serve as the basis of definite arrangement. You will be requested to purchase your tickets when you register upon arrival at the convention.

Event	*Time*	*Cost*
Broadcast "Queen for a Day"	Thursday 11:30 A.M.	None except lunch
Sightseeing trip of City, studios, and Westwood Village with lunch at the beach	Wednesday all day	$7.50
The Turnabout Theater	Wednesday evening	$2.40

HOTELS AND HOUSING

The hotels and housing committee has obtained commitments for comfortable rooms from sixteen of the better and most conveniently located hotels. These commitments may be converted into definite reservations only to the extent that those expecting to attend meet the requirements indicated herein.

Fill out your reservation form, attach your personal check required by the hotel as an advance deposit for your room, and mail on or before February 25. Checks for $5.00 per person should be made payable to V. W. Vandiver, Hotels Chairman. Hotel reservations to be handled by the hotels and housing committee will close on March 1.

Those who can and wish to stay in private homes are encouraged to do so.

Try to avoid requesting a single room. If possible, team up with somebody else and request a double room.

Your arrival on Sunday, March 23, will save you much confusion and will relieve the inevitable congestion expected on Monday, March 24.

	All Rates Subject to Change
Biltmore (Headquarters)	$4.50 and up, Single $6.50 to $10.00, Double
Alexandria	$5.00 to $7.00, Double (1 bed) $6.00 to $7.00, Double (Twin beds) $7.00 to $8.00, Triple (3 beds) $7.00 to $8.00, Triple (2 beds)
Ambassador	No rates quoted
Chapman Park	No rates quoted (All Twin beds)
Clark	$6.00 to $8.00 daily
Commodore	$2.50 to $3.50 daily
Embassy	$3.00 to $4.00 daily
Figueroa	$3.50 daily (All Twin beds)
Hayward	$3.50, Single $5.50, Double
Lankershim	$3.85 to $5.50 (All Double and Twin beds)
Mayfair	$3.85 daily (Twin beds)
Rosslyn	$4.00 to $6.00 (Double and Twins) $4.50 to $7.00 (Triples)
San Carlos	$4.00 daily, Single or Double
Stillwell	$3.00 to $4.00 daily
St. Paul	$3.00 to $4.00 daily
Teris	$3.00 to $4.00 daily
Town House	Approximately $18.50 daily

Correspondence addressed to any of the foregoing hotels will be referred directly to our hotels and housing committee.

Those who prefer auto courts, or hotels other than those listed, are privileged to write at once directly to these establishments for reservations.

Desirable Motor Hotels	*Address*	*Comments*	
El Adobe Motel (Attention Mr. Nelson, Mgr.)	800 W. Garvey Monterey Park	Have several apartments requiring 3 or 4 persons; $3.00 per person.	
Deposit for one day required 15 days in advance.			
Pueblo de Los Angeles	1750 Colorado Blvd., Eagle Rock 41, California	Cottages with double beds	
		Single (2 persons)	$ 5.00
		Double (4 persons)	$ 8.00
		Triple (6 persons)	$13.00
1 day deposit required 3 weeks in advance.			
Alberts Motel	1460 Colorado Blvd., Eagle Rock 41, California	Room for two	$3.00
		Room for three	$4.00
		Room for four	$8.50
1 day deposit required 30 days in advance.			
Grand Motel (Mrs. Smock, Mgr.)	3321 East Colorado Blvd., Pasadena	Room for two	$2.00
		Room for three	$3.00
		Room for four	$4.00
1 day deposit required 30 days in advance.			

All quoted rates for hotels and motor hotels are subject to increase in the immediate future.

Each member will receive a copy of this announcement, with reservation blank, and with minor revisions in the program, in the early part of February.

Following is only a copy of the reservation form which will be mailed separately to each member early in February. The member is to return that form in a specially marked envelope to Harold W. Hoots, 555 South Flower St., Los Angeles, California.]

SAMPLE RESERVATION FORM

Read your announcement,
Fill out and return this form
for
YOUR RESERVATIONS

IMPORTANT: Mail this form with your check on or before February 25, 1947.

FOR YOUR HOTEL ROOM

I request ________________________ at ______________ Hotel
(Number and type of rooms; double or twin beds) (Preference)

March ________________________. Sharing this room with me will be
(dates)

____
(Give name of other person or persons)

I (we) arrive on ______________ at ____________ March ____________;
(Railroad) (Hour) (date)

my check for $______________ is attached.
($5.00 per person)

NOTE: Your reservation and attached check must be received by the committee by March 1, 1947. You should receive confirmation of your reservation and name of hotel by March 15.

For Field Trips

I wish to attend the following field trips: *Check below*

1. Rancho La Brea Fossil Pits and Museum (Monday, March 24) ________
2. California Institute of Technology and its Seismological Laboratory (Geophysicists, Wednesday, March 26) ________
3. Ventura, Santa Barbara, Santa Maria, Bakersfield, Los Angeles (March 28–30) ________
   (a) To Ventura and return Los Angeles (Friday, March 28) ________
   (b) Complete trip (arriving Los Angeles, Sunday evening, March 30) ________

For Entertainment

General Entertainment

Dinner-Dance (Thursday night)—tickets should be purchased and tables should be reserved when you register.

The Drunkard show—Please arrange ________ reservation(s) for me ($2.50 each) for Tuesday night.

Cocoanut Grove (Ambassador Hotel)—Please arrange ________ reservations for me for ________ night (dinner and essentials $6.00–$7.00 per person).

Earl Carroll's Night Club—Please arrange ________ reservation(s) for me for ________ night (average total cost $10.00 per person).

Ladies Entertainment

Ladies Tea—Tuesday 3:00–5:30 P.M. Sight-Seeing Trip (Wednesday)—Please make ________ reservation(s) for me ($7.50 each).

"Queen for a Day" Broadcast (Thursday). Please make ________ reservation(s) for me ($2.40 each).

The Turnabout Theatre (Wednesday night)—Please make ________ reservation(s) for me ($2.40 each).

DISTINGUISHED LECTURE TOUR

S. W. Muller, professor of geology, Stanford University, California, appeared before the following groups between January 6 and 16, 1947, in a lecture tour under the auspices of the distinguished lecture committee of the A.A.P.G. The title of his lecture was, "Permafrost and Engineering Problems."

January	6	New York Academy of Sciences, New York City
	7	The Geology Club, Yale University
	9	Ohio State University, Columbus
	10	University of Wisconsin, Madison
	11	Illinois Geological Survey, Urbana
	13	Tulsa Geological Society
	14	North Texas Geological Society, Wichita Falls
	15	Dallas Geological Society
	16	Houston Geological Society

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 1 (JANUARY, 1947), PP. 196-197

MEMORIAL

BENJAMIN LUTHER PILCHER, JR.

(1906–1946)

The many friends of Ben Pilcher were shocked and grieved by his untimely death on August 8, 1946. He died in a hospital at Albuquerque, New Mexico, as a result of injuries suffered in an automobile accident.

BENJAMIN LUTHER PILCHER, JR.

Ben was born August 19, 1906, in Streator, Illinois. After graduation from high school, he attended Ohio Wesleyan University for a semester and then transferred to the University of Texas. Here he received his B.A. in geology in 1929 and his M.A. in 1931. During his college years he did part-time work for the Texas Bureau of Economic Geology, and in the geophysical department of the Sun Oil Company.

For a short period after graduation, he did statistical work for the R. W. Byram Company of Austin, Texas, and then entered consulting work. He joined the geological staff of The Texas Company at Houston in 1933 and remained there for two years, specializing in subsurface work on the Tertiary of southwest Texas. In 1935 he was transferred to Pampa, Texas, where he became district geologist for the Panhandle area. In 1938, he was called to the division office at Fort Worth, where he carried on regional subsurface studies in north and west Texas and New Mexico. In 1943, he became district geologist for the West Texas-New Mexico district with headquarters at Midland, where he was living at the time of his death. He had established a reputation as a geologist of great ability, and possessed outstanding personal qualities which would have assured his continued rise in his profession. His keen mind and his technical skill will be greatly missed in the oil industry.

In 1935, he married Miss Polly Miles of Kaufman, Texas. Her love and companionship unquestionably contributed largely to his success in life. His constant devotion to his wife and two small daughters was typical of his character.

Ben was endowed with a winning personality, and with an innate love for his fellowman. As a result he had an unusually large circle of friends, both in and outside of the oil industry. He was a lover of the outdoors, and fishing and hunting were his hobbies. Those who accompanied him on his trips afield will remember him as an ideal companion, a true sportsman, and a loyal friend. It was a privilege to know and work with Ben. In a very real sense he is still with us, and will be as long as memory shall last.

Ben was a member of the Presbyterian Church. He joined the A.A.P.G. in 1930, and was affiliated with Sigma Gamma Epsilon, the American Petroleum Institute, and the West Texas Geological Society. He is survived by his wife and two daughters, Margaret Miles and Merle Ann, who now reside in Kaufman, Texas; his mother, Mrs. B. L. Pilcher, and a sister, Miss Iona Smith, both residents of Zitacuaro, Michoacon, Mexico; and a brother, Dr. John F. Pilcher, of Corpus Christi, Texas.

DONALD G. STOOKEY

Fort Worth, Texas
November 25, 1946

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 1 (JANUARY, 1947), PP. 198-200

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

GERALD FRANCIS LOUGHLIN, formerly chief geologist of the United States Geological Survey, Washington, D. C., died on October 22, 1946, at the age of 65 years.

C. Y. LEE, director of the National Geological Survey of China, announces that the Survey is now re-established in its original building at 942 Chukiang Road, Nanking, China

JOHN ZIMMERMAN, JR., has been made chief geologist of the Permanente Cement Company, Permanente, California.

P. E. NARVARTE, consulting geophysicist, is situated at 307 Insurance Building, San Antonio, Texas.

HOWARD A. MEYERHOFF is on an expedition along 500 miles of the eastern Andean front in Argentina. His permanent address is 7 Hampton Terrace, Northampton, Massachusetts.

The Eastern Section of the Association has been officially chartered by the A.A.P.G., succeeding the Eastern Society of Petroleum Geologists. The annual meeting was held at the Mining Club, 33 Broadway, New York City, September 23, 1946. Newly elected officers are: president, BEN F. HAKE, Gulf Oil Corporation, 17 Battery Place,; vice-president, WINTHROP P. HAYNES, Standard Oil Company (New Jersey); secretary, L. G. WEEKS, Standard Oil Company (New Jersey), Room 2150, 30 Rockefeller Plaza; treasurer, WALTER S. OLSON, The Texas Company; all in New York City.

New officers of the Wyoming Geological Association, Casper, Wyoming, are as follows: president, CHARLES T. JONES, Stanolind Oil and Gas Company; 1st vice-president, ROLLAND W. MCCANNE, Ohio Oil Company; 2d vice-president, THOMAS C. HIESTAND, Cities Service Oil Company; secretary-treasurer, WILLIAM A. THOMPSON, The Texas Company. Visiting geologists and friends are welcome at both the evening meetings and the luncheons which are held each Friday noon at the Townsend Hotel, Casper.

A special election was held on November 4, 1946, by the New Orleans Geological Society to fill the offices of president and vice-president left vacant by R. R. COPELAND and R. L. DENHAM, respectively, who have moved from the area served by the society. GORDON I. ATWATER, independent consultant, was elected president, and J. L. PATTON, Humble Oil and Refining Company, was chosen vice-president.

At the first meeting of the Eastern Section of the Association, November 25, at the Mining Club, New York City, WALLACE E. PRATT delivered a stimulating address to an interested audience on the subject "Petroleum in the Continental Shelves." About 45 members and 25 guests were in attendance.

L. G. WEEKS, of the Standard Oil Company (New Jersey), New York City, attended the Second Congress of the Pan American Institute of Mining Engineers and Geologists, held at Rio de Janeiro, Brazil, during the first two weeks of October, where he presented a paper on the "Paleogeographies of South America," illustrated by 16 paleogeographic-facies maps ranging from the Cambrian to the Pliocene. The paper contained a bibliography of about 365 items.

RAY E. MORGAN, formerly with Compania de Petroleos del Valle del Magdalena, Bucaramanga, Colombia, may be addressed in care of the Socony-Vacuum Oil Company, Apartado Aereo 4034, Bogota, Colombia, S. A. After January 1, he will be enjoying a state-side vacation and can be reached at 7411 Atwood, Overland Park, Kansas.

GILBERT P. MOORE, formerly with the Auto Ordnance Corporation, is now with the oil firm of Moore and Brown, Dallas, Texas.

A. I. LEVORSEN has been appointed dean of the newly established School of Mineral Sciences of Stanford University, California. The new school combines the former department of geology, of the School of Physical Sciences, with the former department of mining, of the School of Engineering. Levorsen was recently elected president of the Geological Society of America.

PARKE D. SNAVELY, JR., following his discharge from the Navy, returned to the U. S. Geological Survey and may be addressed at Box 52, Neskowin, Oregon.

GROVER E. MURRAY, JR., presented his paper on "The Cenozoic Deposits of Mississippi and Adjacent Areas" before the Tulsa Geological Society, meeting in Tyrrell Hall, University of Tulsa, on November 18, 1946.

WAYNE C. DAVISON, consulting geologist, has changed his permanent office address from Houston, Texas, to 224 Denham Building, Denver, Colorado.

MORRIS B. WHITE, formerly with the Princeton Refining Corporation, is now with the Louisiana Iron and Supply Company, 2900 Mansfield Road, Shreveport, Louisiana.

CARL WIEDENMAYER has changed his address from Frauenfeld, Switzerland, to Società Petrolifera Italiana, Fornovo Taro (Parma), Italy.

HOMER E. ROBERTS has moved fro n Caracas to San Cristobal, Estado de Tachira, Venezuela, where he is employed by the Caribbean Petroleum Company.

HARRY E. LILLIBRIDGE, formerly with the Eason Oil Company, is now an independent consulting geologist, 1207 Ramona Drive, Enid, Oklahoma.

MILTON W. CORBIN has resigned from the Skelly Oil Company to accept a position as district geologist for The Chicago Corporation, Box 1047, Shreveport, Louisiana.

RAYMOND C. BECKER, formerly chief of the Fuels Branch, Mining and Geology Division, Natural Resources Section, GHQ-SCAP, Tokyo, Japan, is back in Denver with the U. S. Geological Survey.

CARL W. HUBMAN has moved from Corpus Christi, Texas, to Apartado 877, Bogota, Colombia, where he is employed by the Texas Petroleum Company.

F. P. HURRY was released from the Service October 20, 1946, and is now working for the Carter Oil Company, Box 837, Craig, Colorado.

E. A. RITTER, formerly of Basle, Switzerland, may now be addressed in care of Shell-Mex Brazil Limited, Caixa Postal 252, Rio de Janeiro, Brazil.

LIEUTENANT COLONEL EDWARD W. JOHNSON, whose terminal leave from service with the Army Signal Corps expired December 22, has accepted employment in a geological capacity at the Squier Signal Laboratory, Fort Monmouth, New Jersey.

GEORGE DICKINSON has about completed his assignment with the Diadema Argentina

S. A. de Petróleo in Comodoro Rivadavia, and after January 15, 1947, may be addressed c/o First and Merchants National Bank of Richmond, Richmond, Virginia.

SAMUEL H. DOLBEAR, president, REGINALD G. BOWMAN and ARTHUR S. HECHT, representing the firm of Behre Dolbear & Company of New York City, have been on a mission in China since early August. The firm has been engaged by the National Resources Commission of China to make a detailed study of tin, tungsten, and antimony deposits, and the corresponding industries of China.

F. STEARNS MACNEIL, United States Geological Survey, left December 1, to take charge of geological mapping operations on the island of Okinawa. His address for approximately the next six months will be: Okinawa Geological Survey, Engineer Section, RYKOM, APO 331, c/o Postmaster, San Francisco, California.

At the annual meeting of the Paleontological Research Institution, held October 12, 1946, at its headquarters in Ithaca, New York, the following officers were elected for the coming year: president, RALPH A. LIDDLE, Fort Worth, Texas; vice-president, AXEL A. OLSSON; secretary, REBECCA S. HARRIS; treasurer, GILBERT D. HARRIS; assistant treasurer, KATHERINE V. W. PALMER. Construction of the new building is still held in abeyance owing to unsettled labor conditions. So far, however, these conditions have not interfered seriously with the completion of the Bulletin on the Jackson Eocene formation or the monographs of Paleontographica Americana.

Under the leadership of E. C. PARKER, Continental Oil Company, A. N. MURRAY, University of Tulsa, and MALCOLM C. OAKES, Oklahoma Geological Survey, the Oklahoma City Geological Society recently sponsored a field trip to north-central Oklahoma. Starting at Ponca City, the itinerary included examination of a section from the top of the Big Blue series (Lower Permian) to the Lenapah of the Des Moines series (Pennsylvanian), ending near Tulsa, Oklahoma. Details of this section are described in a guidebook issued by the Society. Approximately 90 geologists from the Mid-Continent area attended.

George S. Buchanan has been named general manager of the Gulf Coast Division of the Sohio Petroleum Company, Houston, Texas.

HENRY CARTER REA has resigned as chief geologist of the Bay Petroleum Corporation and has opened a consulting office in Casper, Wyoming.

JOE BEARD is employed by SCHWEER and HARDISON, consulting petroleum geologists of Wichita Falls, Texas. He was recently released from active duty with the U. S. Marine Corps.

RAY G. GREENE has been appointed as manager of lands and leases by the Union Oil Company of California.

SUMNER T. PIKE is a member of the U. S. Atomic Energy Commission, Washington, D. C. He was formerly a member of the U. S. Securities and Exchange Commission, Philadelphia, Pennsylvania.

CAROL WINTHROP PAYNE may be addressed in care of Lane Wells Company, New Iberia, Louisiana.

CHARLES R. RIDER is president of the Twin Oil Corporation, 805 Continental Building, Dallas 1, Texas.

PROFESSIONAL DIRECTORY

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

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Mining Geologist
Midland Savings Building

1st Vice-President - - - - - C. A. Heiland
Heiland Research Corporation

2nd Vice-President - - - - Robert McMillan
Geophoto Services, Inc.
136 East Twentieth Ave.

Secretary-Treasurer - - - - - A. W. Cullen
1024 Continental Oil Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - - Jack Hirsch
Box 442, Mattoon, Illinois

Vice-President - - - - - - - - E. E. Rehn
Sohio Petroleum Company
Box 537, Mt. Vernon

Secretary-Treasurer - - - - John B. Patton
Magnolia Petroleum Company
Box 535, Mt. Vernon

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - E. Gail Carpenter
Consulting, 240 N. Pinecrest

Vice-President - - - - - - - Lee H. Cornell
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - - - Don W. Payne
Sinclair Prairie Oil Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - T. H. Philpott
Carter Oil Company

Vice-President - - - - - - - Brame Womack
Sohio Petroleum Corporation

Secretary-Treasurer - - - - - - - J. Ed. Lytle
Union Producing Company

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

FLORIDA

SOUTHEASTERN GEOLOGICAL SOCIETY
Box 841
TALLAHASSEE, FLORIDA

President - - - - - - - - - - - I. J. Reed
The California Company

Vice-President - - - - - - - - Walter B. Jones
Geological Survey of Alabama

Secretary-Treasurer - - - - - - H. A. Sellin
Magnolia Petroleum Company

Meetings will be announced. Visiting geologists and friends are welcome.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - Charles W. Honess
Gulf Refining Company, Box 774

Vice-President - - - - - - - - J. Albert Brown
Sohio Petroleum Co.
Owensboro, Kentucky

Secretary-Treasurer - - - - - - F. H. Latimer
Sun Oil Company
Evansville, Ind.

Meetings will be announced.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - Gordon I. Atwater
Consultant, 1034 Whitney Building

Vice-President and Program Chairman - - -
- - - - - - - - - - - - - J. L. Patton
Humble Oil and Refining Company

Secretary-Treasurer - - - - - Philip R. Allin
Gulf Refining Company, Harvey, La.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - - - J. A. Moore
Union Sulphur Company, Sulphur

Vice-President - - - - - - - James M. Bugbee
Shell Oil Company, Inc.

Secretary - - - - - - - - - - Lloyd D. Traupe
Ohio Oil Company, Lafayette

Treasurer - - - - - - - - - D. E. Newland
Magnolia Petroleum Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - - Rex P. Grant
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
Vice-President - - - - - Richard H. Wolcott
Sohio Petroleum Company, Mt. Pleasant
Secretary-Treasurer - - - - Charles K. Clark
Pure Oil Company
402 2d Natl. Bank Bldg., Saginaw
Business Manager - - - Kenneth A. Gravelle
Gulf Refining Company, Box 811, Saginaw

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY

JACKSON, MISSISSIPPI

President - - - - - - - Frederic F. Mellen
Mellen & Monsour
Box 2571, W. Jackson Sta.

Vice-President - - - - - - - - J. B. Wheeler
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - - - H. L. Spyres
Skelly Oil Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY

ARDMORE, OKLAHOMA

President - - - - - - - Robert W. Kline
Sinclair Prairie Oil Company, Box 978

Vice-President - - - - - - - - B. W. James
Phillips Petroleum Company, Box 958

Secretary-Treasurer - - - Murrell D. Thomas
The Texas Company, Box 539

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - Gerald C. Maddox
Carter Oil Company

Vice-President - - - - - - - Harold J. Kleen
Skelly Oil Company

Secretary-Treasurer - - - - Frederick H. Kate
Shell Oil Company, Inc.
965 First National Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

SHAWNEE GEOLOGICAL SOCIETY

SHAWNEE, OKLAHOMA

President - - - - - - - - - Delbert F. Smith
Oklahoma Seismograph Company

Vice-President - - - - - - - Henry A. Campo
Atlantic Refining Company

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY

TULSA, OKLAHOMA

President - - - - - - - - - John G. Bartram
Box 591, Stanolind Oil and Gas Co.
1st Vice-President - - - - - Russell S. Tarr
Independent, Beacon Building
2nd Vice-President - - - - - John C. Maher
U. S. Geological Survey
Secretary-Treasurer - - - - - John R. Crain
Ashland Oil and Refining Company
Editor - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY

CORPUS CHRISTI, TEXAS

President - - - - - - - - W. E. Greenman
The Texas Company, 902 Jones Building

Vice-President - - - - - - - Dale L. Benson
Sinclair Prairie Oil Company, Box 480

Secretary-Treasurer - - - - - - O. G. McClain
Consultant, 224 Nixon Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS GEOLOGICAL SOCIETY

DALLAS, TEXAS

President - - - - - - - - - John W. Clark
Magnolia Petroleum Company, Box 900
Vice-President - - - - - - - Willis G. Meyer
DeGolyer and MacNaughton, Continental Building
Secretary-Treasurer - - - - John M. Clayton
Seaboard Oil Company, 1400 Continental Building
Executive Committee - - - - Fred H. Wilcox
Magnolia Petroleum Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - T. H. Shelby, Jr.
Humble Oil and Refining Company

Vice-President - - - - - - - George N. Ely
Continental Oil Company
907 Peoples Bank Building

Secretary-Treasurer - - - - - B. F. Murphy
Amerala Petroleum Corporation
Box 2026

Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - Shapleigh G. Gray
Consultant, 1713 Esperson Building

Vice-President - - - - - Charles H. Sample
J. M. Huber Corporation
721 Bankers Mortgage Bldg.

Secretary - - - - - - - - - - A. F. Childers
Gulf Oil Corporation, Box 2100

Treasurer - - - - - - - - Wayne Z. Burkhead
Union Oil Company of California
1134 Commercial Bldg.

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - - - - Thornton Davis
Peerless Oil and Gas Company
2023 Alamo National Building

Vice-President - - - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Secretary-Treasurer - - - - - Paul B. Hinyard
Shell Oil Company, Inc.
2000 Alamo National Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - John H. Wilson
Independent Exploration Company
2210 Ft. Worth National Bank Bldg.

Vice-President - - - - - - Edwin M. Rowser
The Texas Company, Box 1720

Secretary-Treasurer - - S. K. Van Steenbergh
Sinclair Prairie Oil Company
901 Fair Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - - - Dolph S. Simic
Bay Petroleum Corporation

Vice-President - - - - - - - Lynn L. Harden
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - D. T. Richards
George W. Graham

Meetings: Each week, Tuesday, 12:30 P.M., Texas Electric Auditorium; Each month, first Thursday evening. Special night meetings announced. All geologists always welcome.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - - - B. A. Ray
Consulting, Box 1385

Vice-President - - - - - - - W. J. Hilseweck
Gulf Oil Corporation, Box 1150

Secretary-Treasurer - - - - Charles A. Shaw
Forest Oil Corporation, Box 366

Meetings will be announced.

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2605

President - - - - - - - - Veleair C. Smith
1901 Kanawha Valley Building

Vice-President - - - - - - - W. B. Maxwell
United Fuel Gas Company, Box 1273

Secretary-Treasurer - - - - - - R. L. Alkire
605 Union Building

Editor - - - - - - - - - - - J. D. Castner
Box 1433

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P. O. Box 545

President - - - - - - - - Charles T. Jones
Stanolind Oil and Gas Company

1st Vice-President - - - Rolland W. McCanne
Ohio Oil Company

2nd Vice-President (Programs) Thomas C. Hiestand
Cities Service Oil Company

Secretary-Treasurer - - William A. Thompson
The Texas Company

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special Meetings by announcement.

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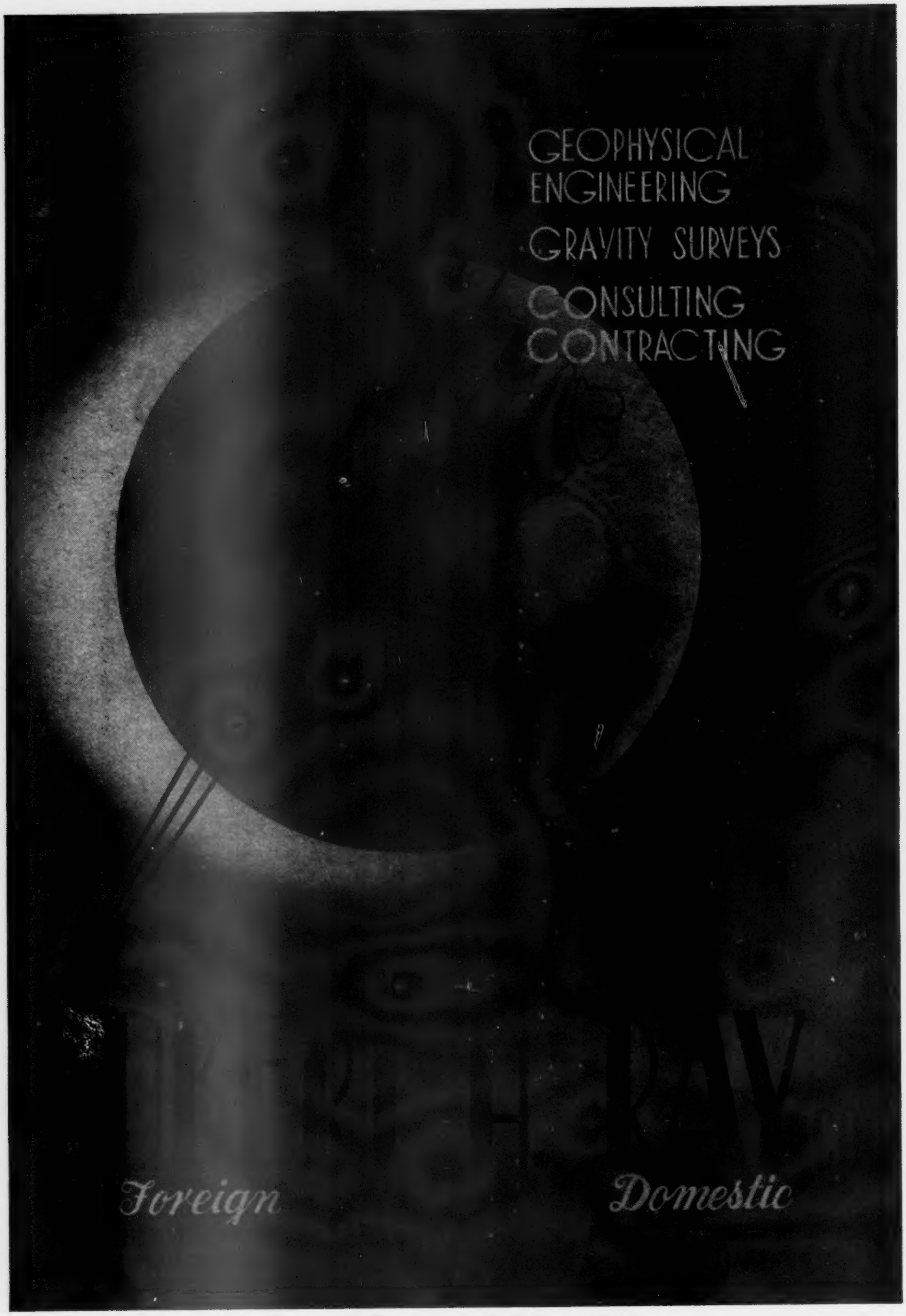
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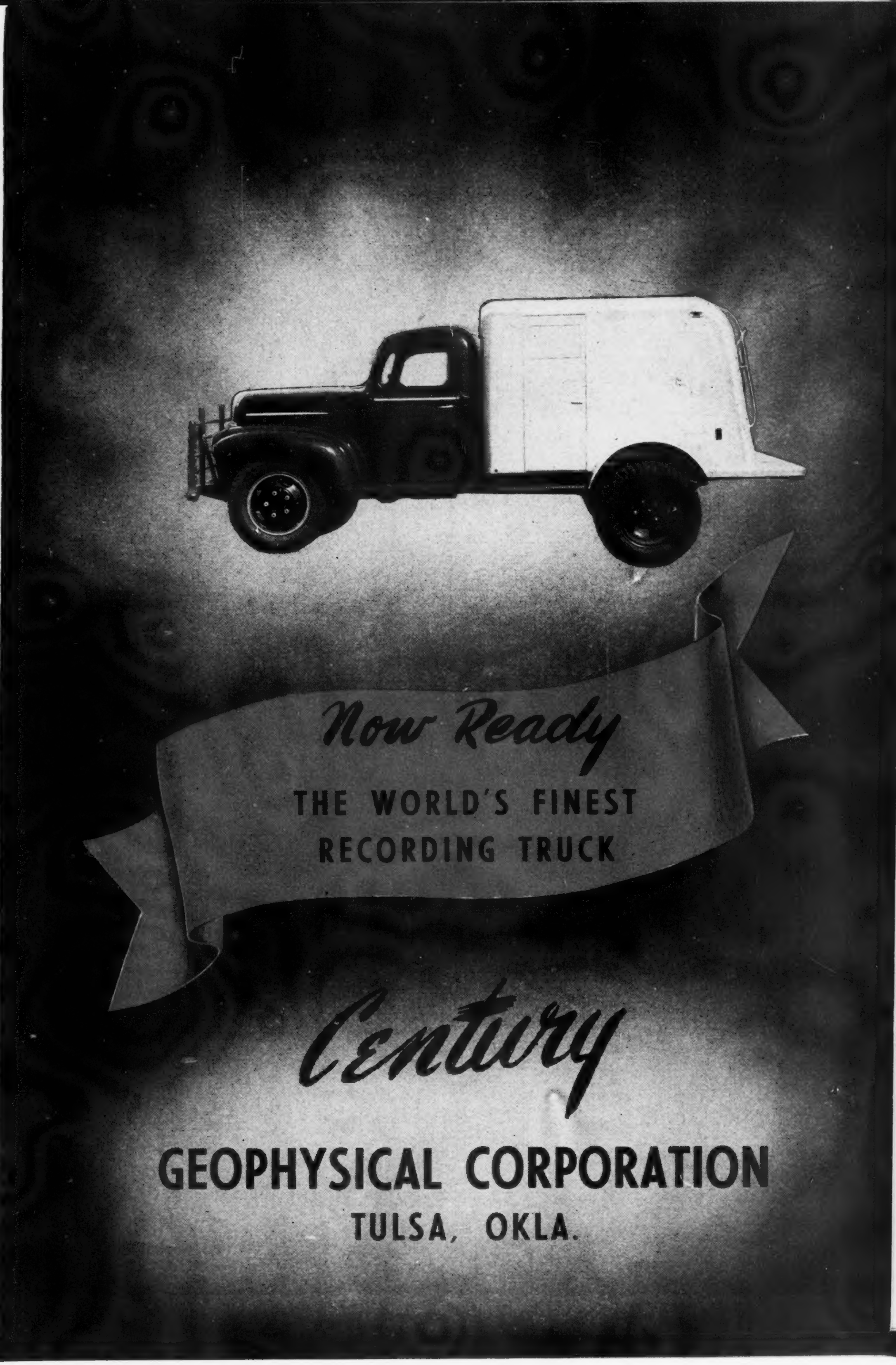
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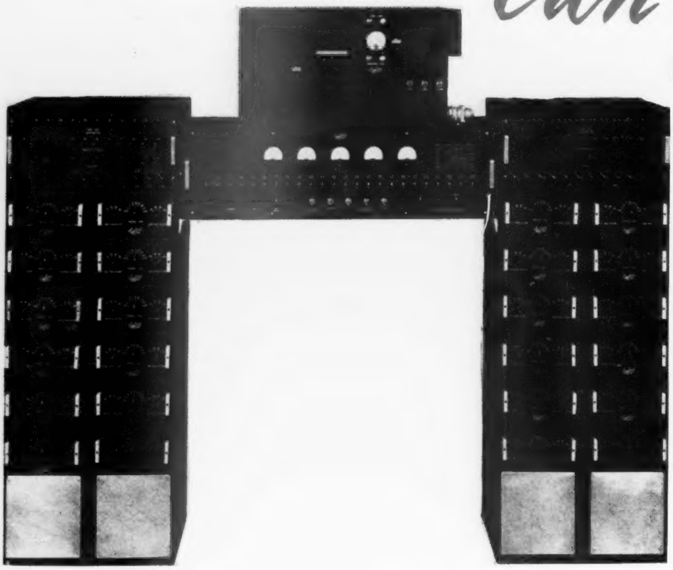

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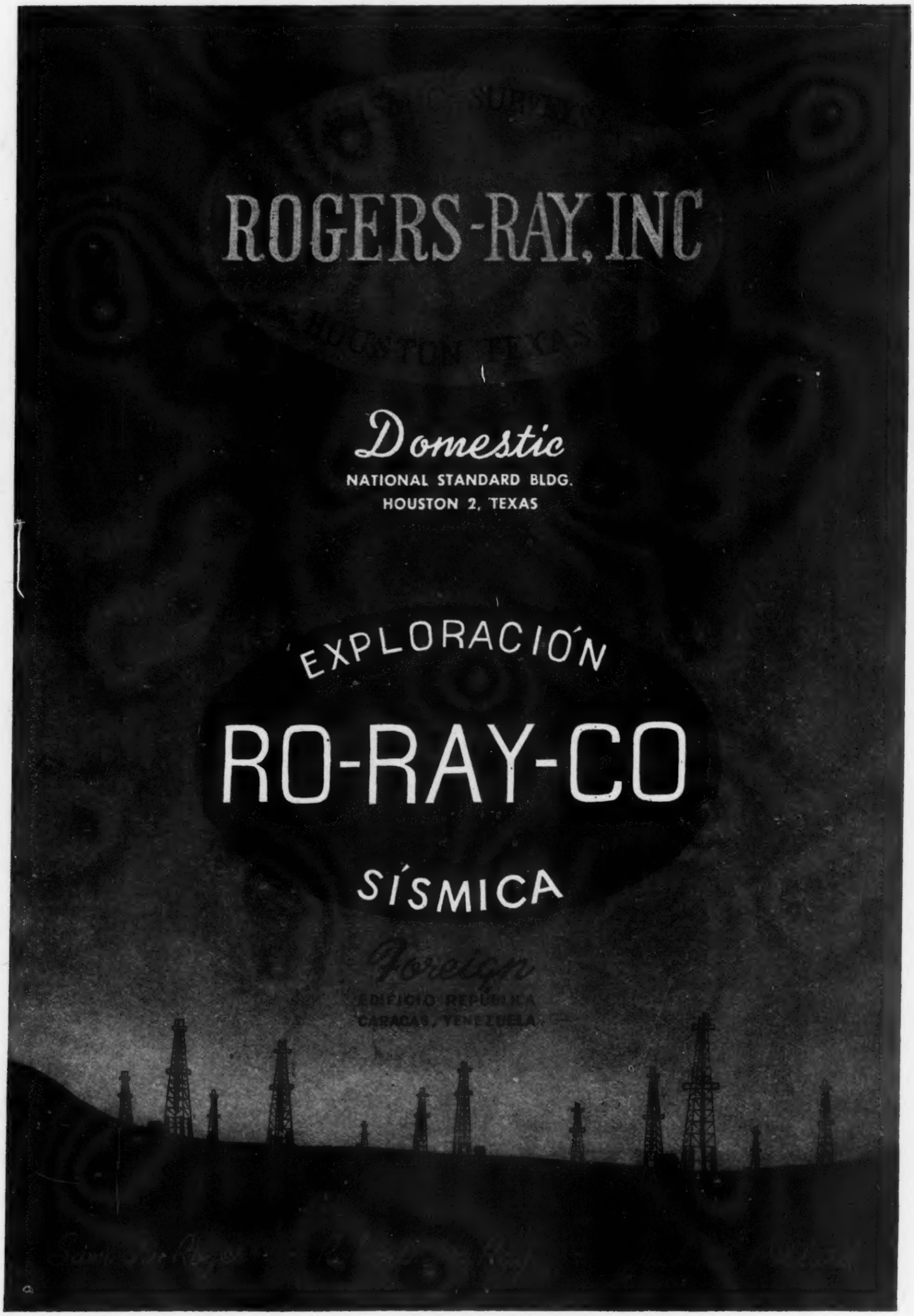
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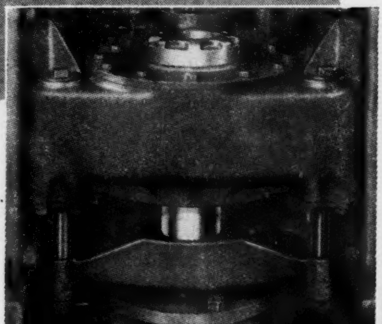

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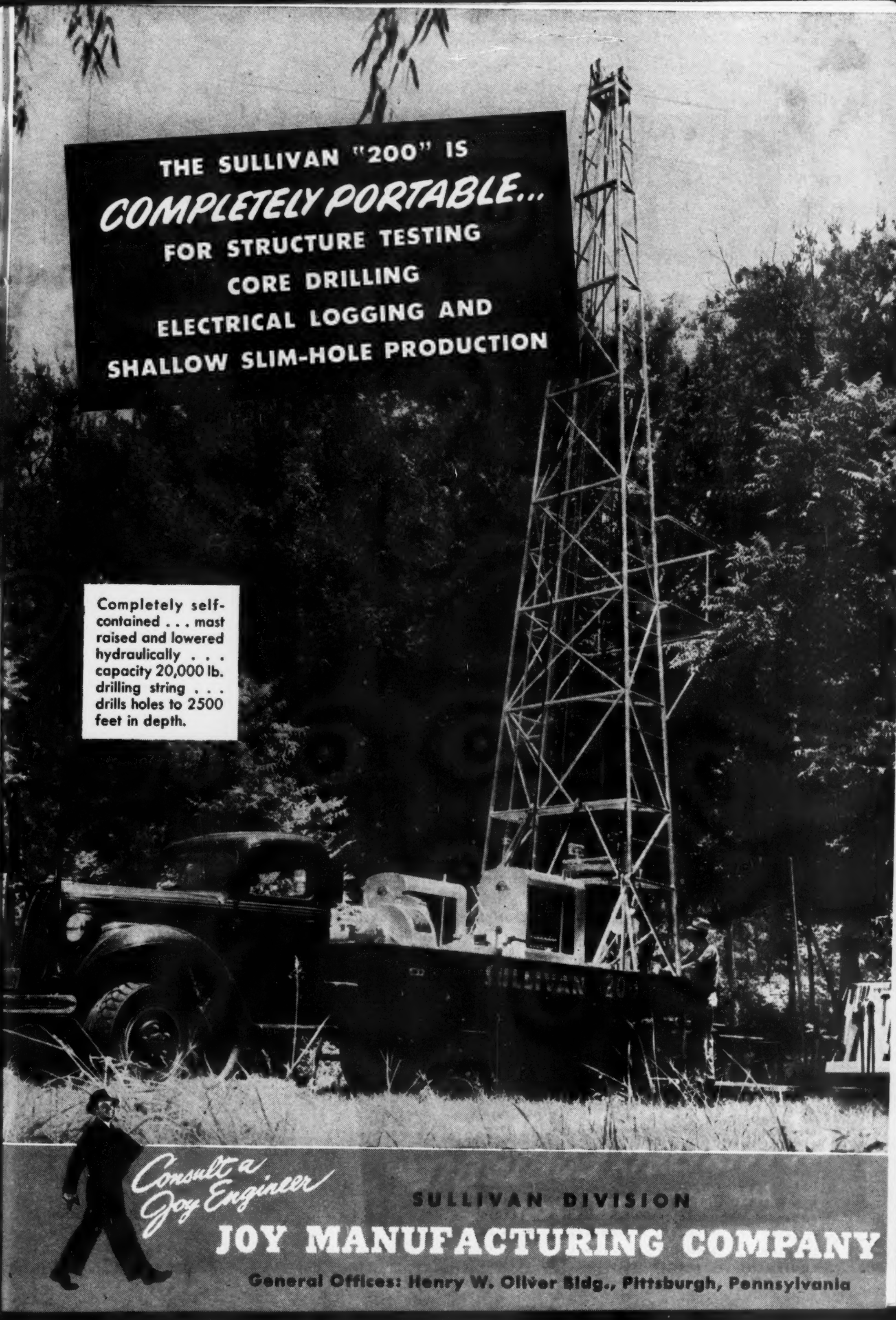
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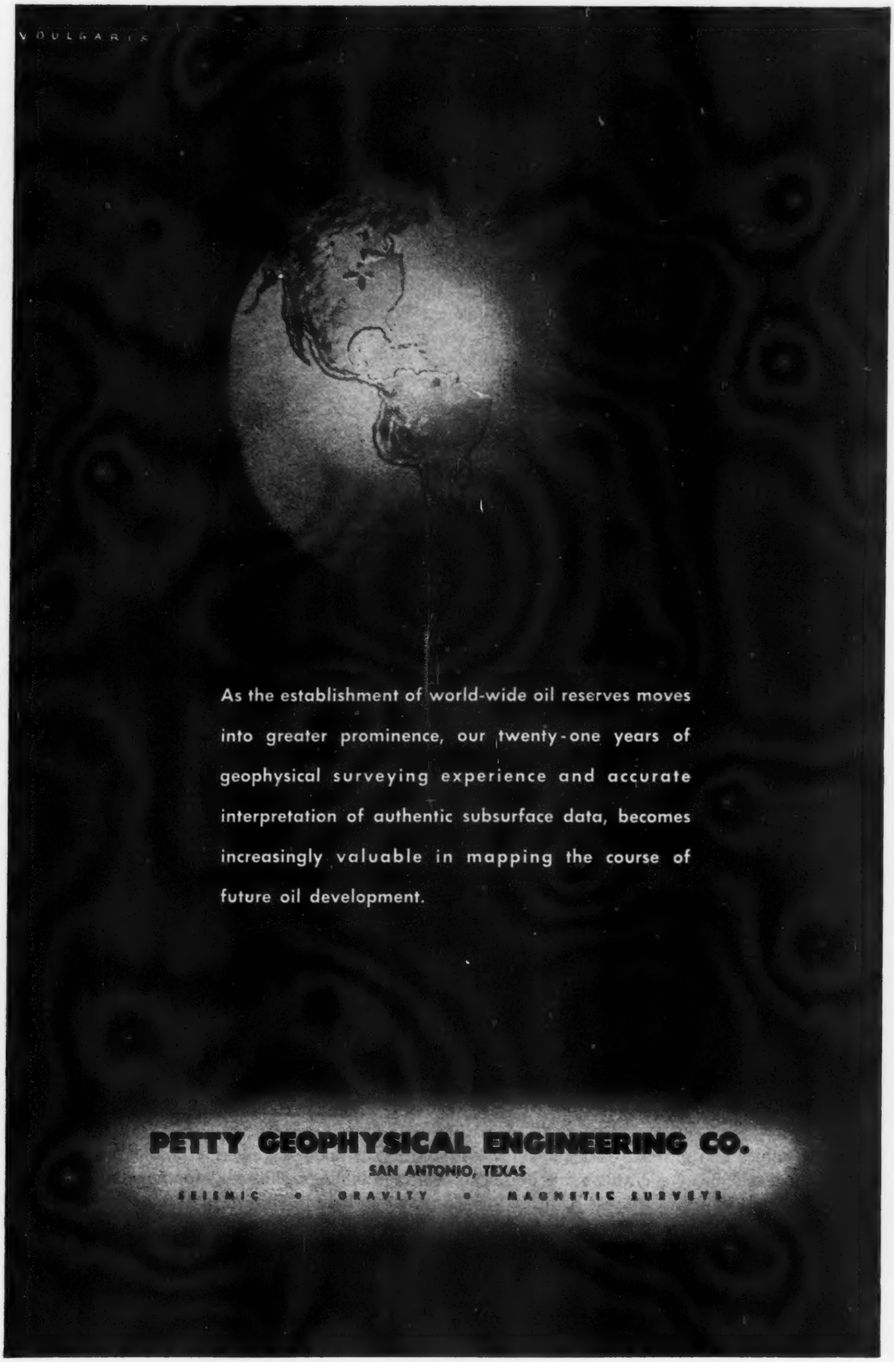
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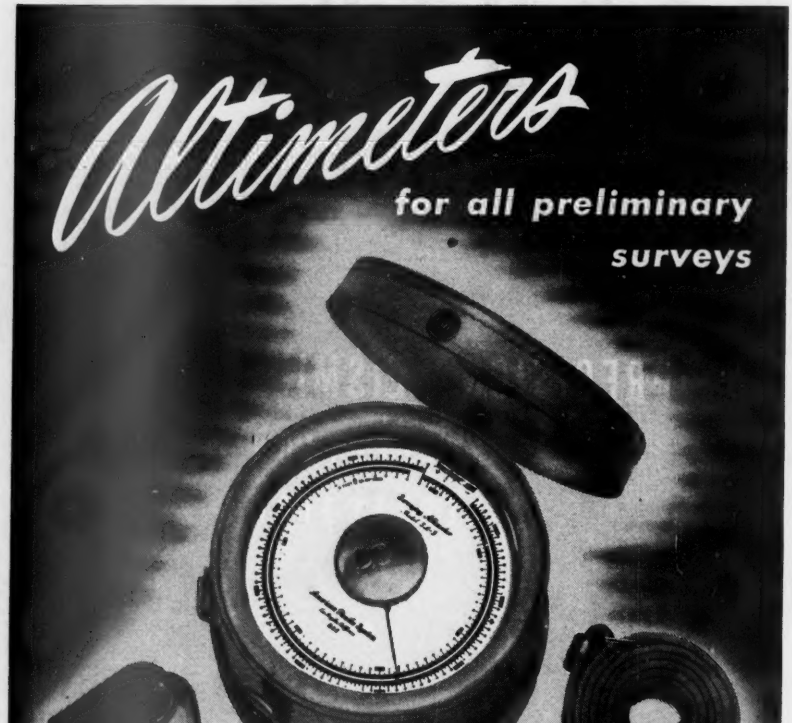
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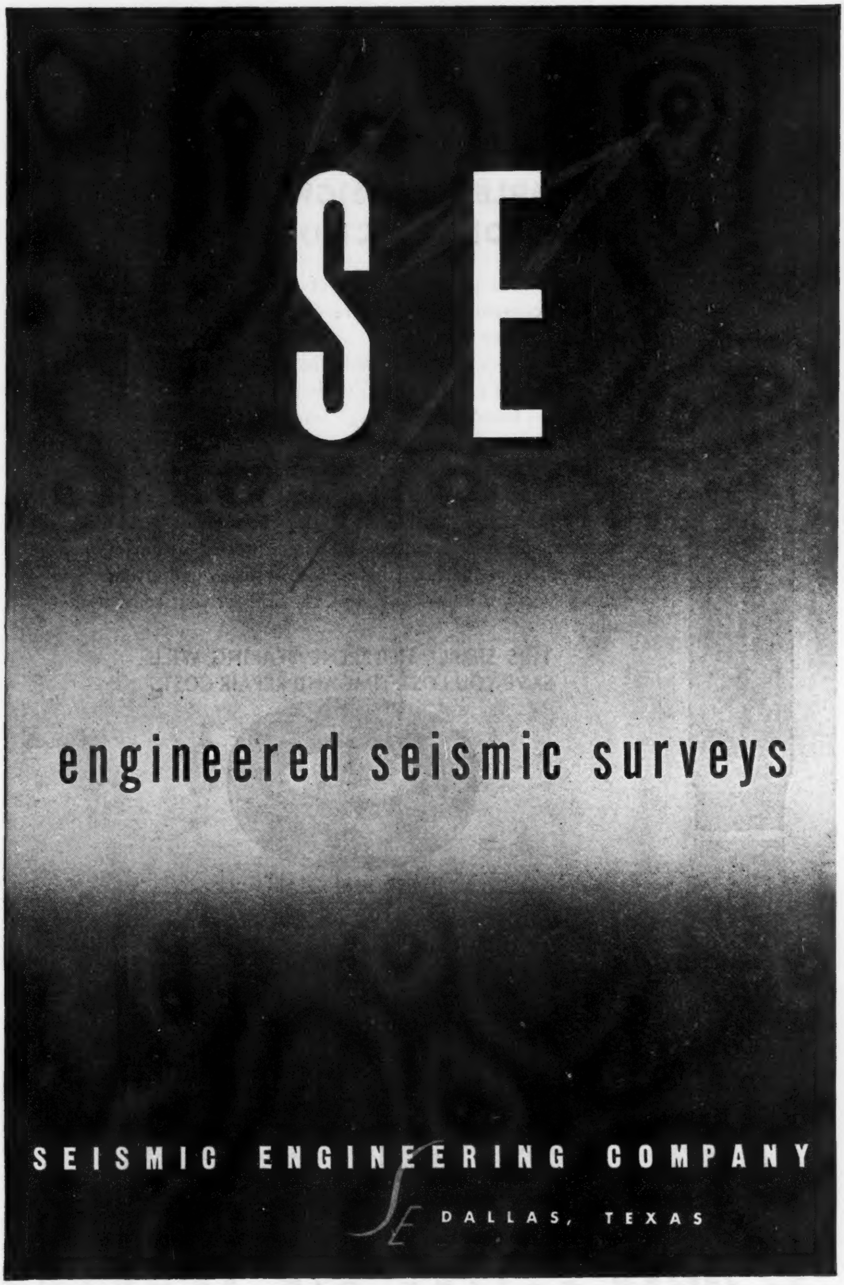
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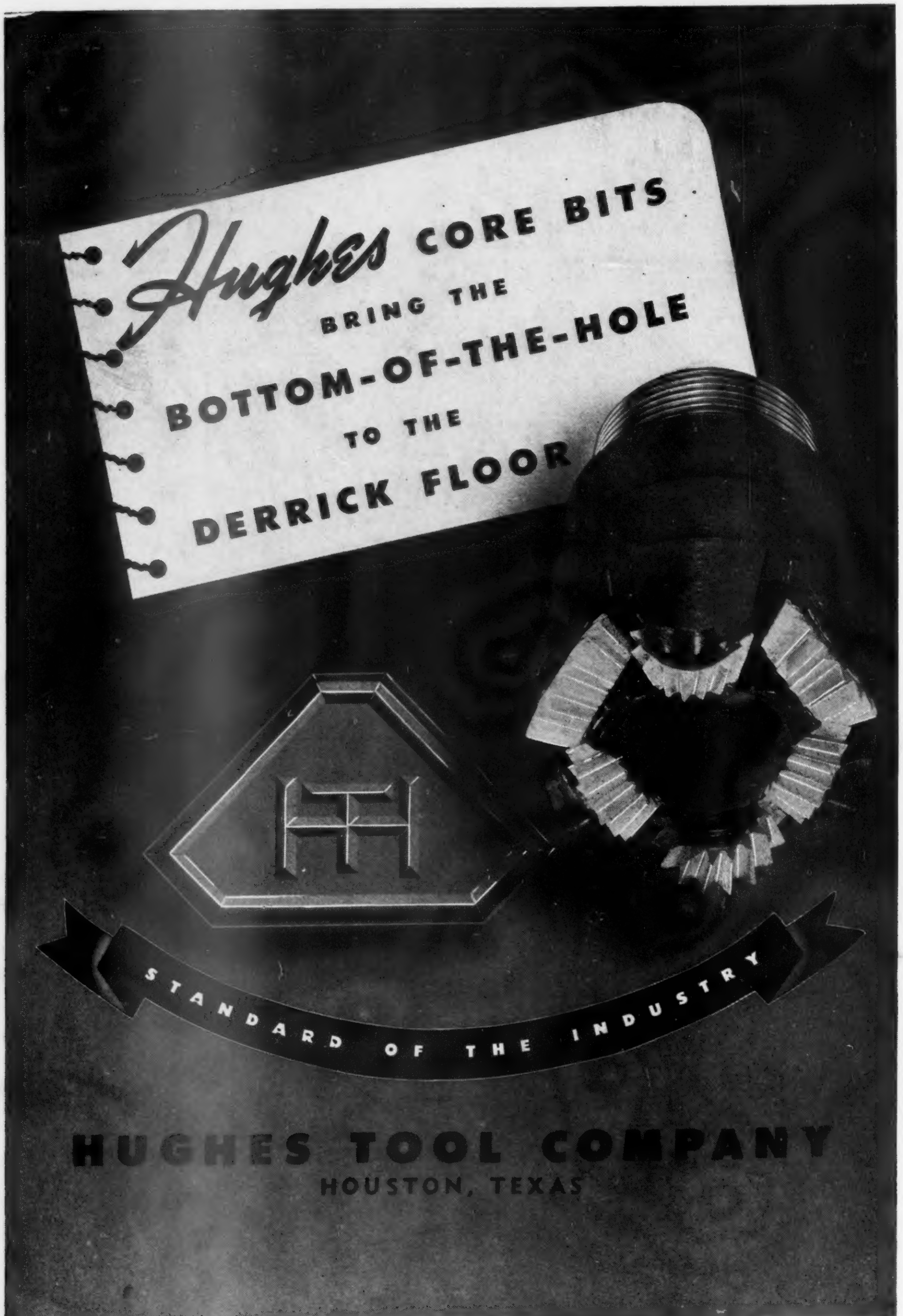
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